CaRFG Performance and Compatibility Test Program

Report of the Performance Subcommittee of the California Reformulated Gasoline Advisory Committee

California Environmental Protection Agency

Air Resources Board

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California Reformulated Gasoline:

Performance and Compatibility Test Program

California Environmental Protection Agency
Air Resources Board
March 1996

Acknowledgments

This is to acknowledge the many people who contributed to this report.

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INTRODUCTION AND BACKGROUND

A. Introduction

This report discusses the California reformulated gasoline (referred to as CaRFG) performance and compatibility test program of on-road vehicles and off-road vehicles and equipment. The on-road vehicles consisted of passenger cars, light-duty trucks and vans, and medium- and heavy-duty trucks. The off-road vehicles and equipment consisted of utility, lawn, and garden equipment, pleasure craft and small marine engines, industrial, construction, and agriculture equipment, personal watercraft, and snowmobiles. In addition, various manufacturers tested parts from vehicles (e.g., carburetors and service equipment such as dispensing nozzles).

Motor vehicles and other gasoline-powered equipment are responsible for more than half of the smog-forming pollutants in California. To address these problems, the Air Resources Board (ARB) has adopted stringent emission control regulations on motor vehicles, gasoline-powered equipment, and their fuels. In 1991, the ARB adopted the CaRFG regulations which include 8 fuel specifications (See the *California Phase 2 Reforumlated Gasoline Staff Report)*. This program will substantially reduce pollutants from on-road and off-road motor vehicles. These reductions are needed if California is to meet its obligations in the State Implementation Plan, which is required by the amendments to the federal Clean Air Act.

1. California Reformulated Gasoline Advisory Committee

In 1994, the ARB formed the California Reformulated Gasoline Advisory Committee (Committee). The Committee is a group of more than 70 representatives from industry, public interest groups, and government agencies. For more than a year, the Committee has been working to help ensure a smooth transition to CaRFG. The Committee has been meeting quarterly and will continue meeting through 1996. (See Appendix 1 for *Advisory Committee Members*.)

The Committee advises the ARB on issues concerning the compatibility of CaRFG with vehicles and equipment, the transition to CaRFG in the distribution and marketing systems, and the public's acceptance of CaRFG. To research and monitor these issues, the Committee formed the Performance, Transition, and Public Education Subcommittees. These subcommittees are continuing to work closely with the ARB in implementing the CaRFG regulations.

Performance Subcommittee. The goal of the Performance Subcommittee (Subcommittee) is to help design fuel testing plans to evaluate the performance and compatibility of CaRFG in on-road motor vehicles, fuel storage systems, and off-road vehicles and equipment. In addition, the Subcommittee has also reviewed the other test programs sponsored by industry.

The members of the Subcommittee include technical experts from the motor vehicle manufacturing and petroleum industries, distribution and marketing associations, government officials, consumer and public interest groups, fleet administrators and equipment manufacturers. (See Appendix 2 for *Performance Subcommittee Members*.)

The Subcommittee provided guidance on the design of the on-road and off-road test programs and helped coordinate the available private and government resources for the test programs. The Subcommittee met every two months and more frequently when necessary, made decisions through consensus, and as problems arose, identified potential solutions.

At its first meeting in July 1994, the Subcommittee commented on the CaRFG test protocol which tested the performance and compatibility of CaRFG through in-use testing of on-road and off-road vehicles, non-vehicle engines, equipment, and fuel system components.

From the test programs, data on vehicle descriptions and fuel system components that failed or malfunctioned were collected. The Subcommittee created a technical review panel to evaluate the incident data collected on the vehicles in the test program. The technical review panel categorized the data according to whether the fuel caused, potentially caused, or did not cause the need for the repair. The members of the technical review panel are from the California Bureau of Automotive Repair, General Motors, Ford, Chrysler, Chevron, Texaco, Shell, Exxon, and the ARB. (See Appendix 3 for *Technical Review Panel Members*.)

Baseline data from the historical maintenance records and historical fueling records were obtained from the same organizations that operated the fleets in the test programs. In addition, data were collected from the fueling records of the test vehicles while in-use. Laboratory dynamometer tests were conducted on selected vehicles in the On-Road test program to further evaluate expected fuel economy of CaRFG.

B. Air Quality

California has severe air quality problems, and emissions from motor vehicles and their fuels are major contributors to these problems. Motor vehicle emissions are the primary source of compounds that react in the atmosphere to form ozone or smog. Motor vehicle emissions also contain toxic air contaminants that increase the risk of cancer to residents in the state.

1. Violations of State Ambient Air Quality Standards

Both the United States Environmental Protection Agency (U.S. EPA) and the ARB have established ambient air quality standards for six pollutants, which are referred to as criteria pollutants. These criteria pollutants are carbon monoxide (CO), lead, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone, and particulate matter. Motor vehicle emissions contribute to violations of the federal and state ambient air quality standards for carbon monoxide, nitrogen dioxide, sulfur dioxide, and ozone. These standards are exceeded in varying degrees by pollutant and by location throughout California.

To comply with these standards and achieve healthful air quality throughout the state, the ARB has implemented an aggressive program to substantially reduce motor vehicle emissions, including changing the specifications for motor vehicle fuels.

2. Motor Vehicle Emissions

Criteria Pollutants. Some criteria pollutants, like CO, are emitted from a source. Other criteria pollutants, like ozone, are formed in the atmosphere from precursors that are directly emitted from a source. The precursors that form ozone are volatile organic compounds (VOCs) and oxides of nitrogen (NO_x). Motor vehicles are the major source of CO emissions and ozone precursors in California. More than 50 percent of California’s precursor emissions come from gasoline-powered vehicles and equipment. (See Appendix 4 for Emission Data.)

Toxic Air Contaminants. Motor vehicles also emit a variety of toxic air contaminants. These include benzene, acetaldehyde, formaldehyde, and 1,3-butadiene. Benzene is also present in gasoline vapors which are released during vehicle fueling and operation, and during the storage and transport of gasoline.

C. California Reformulated Gasoline Regulations

1. Requirements

Starting on March 1, 1996, all gasoline shipped from production or import facilities for consumption in California must meet the CaRFG requirements. Gasoline shipped from terminals must comply by April 15, 1996. Gasoline supplied from all other facilities must comply by June 1, 1996. The CaRFG regulations establish limits for the following 8 specifications for gasoline:

- aromatic hydrocarbon content
- benzene content
- olefin content
- oxygen content
- Reid vapor pressure (RVP)
- sulfur content
- 50-percent distillation temperature (T50)
- 90-percent distillation temperature (T90)

Table 1 lists the CaRFG specifications. For each specification, except RVP and oxygen content, a refiner may choose either the "flat” limit or the "averaging" limit. The flat limits apply to every batch of finished gasoline. During any 180-day period, the average for each property cannot exceed the average limit. Alternative values of flat or averaging limits can be used if the refiners can demonstrate that the alternative limits have equivalent emission benefits. However, the "cap limits" apply to all gasoline throughout the distribution system and cannot be exceeded at any time.

Table 1
Specifications for California Reformulated Gasoline
(effective in 1996)

Property	Flat Limits	Averaging Limits	Cap Limits
RVP, psi	7.0	None	7.0
Sulfur, ppmw	40	30	80
Benzene, vol%	1.00	0.80	1.20
Aromatics, vol%	25	22	30
Olefins, vol%	6.0	4.0	10
Oxygen, wt%	1.8 to 2.2	None	to 2.7
T50, ^{0}F	210	200	220
T90, ^{0}F	300	290	330

Source: California Code of Regulations. Title 13. sections 2262.1 to 2262.7.

2. Emission Benefits

The use of CaRFG will immediately reduce emissions of criteria and toxic air contaminants from all existing on-road and off-road gasoline-burning vehicles and equipment. It will produce the largest emission reductions of any control measure in the last decade. These standards will reduce evaporative and exhaust emissions of VOCs and toxic compounds. They will also reduce NOx, a precursor to ozone formation, CO, and oxides of sulfur (SO_x) in motor vehicle exhaust. Table 2 shows the predicted emission reductions for on-road and off-road gasoline-powered vehicles and gasoline marketing operations.

Criteria Pollutants. The use of CaRFG will reduce VOC, NOx, and CO emissions by improving combustion, enhancing exhaust catalyst activity, and decreasing the evaporation of gasoline. In addition, because the specifications limit the sulfur content of gasoline, SOx emissions from the use of gasoline will be reduced by about 80 percent. (See Appendix 5.) The reductions will occur immediately in 1996 from on-road and off-road motor vehicles.

Toxic Air Contaminants. The CaRFG standards will affect the emissions of 4 toxic compounds: benzene, 1,3-butadiene, formaldehyde, and acetaldehyde. Of these 4, benzene and 1,3-butadiene are the most potent. Hence, they are of more concern than the other 2.

Toxic compounds are emitted through evaporation and motor-vehicle exhaust. In 1996 through 2000, the ARB staff expects about a 50 percent reduction in evaporative benzene emissions as a result of the benzene specification. (See Appendix 6.) The use of

CaRFG will reduce the overall potential cancer risk from motor vehicle emissions by 30 to 40 percent. (See Appendix 7.)

Table 2
Predicted Emission Benefits of California Reformulated Gasoline
(Projected for 1996)

Market Segment	**Volatile Organic Compounds (VOC)**		**Oxides of Nitrogen (NOx)**		**Carbon Monoxide (CO)**	
	TPD	Percent	TPD	Percent	TPD	Percent
On-Road Vehicles[1]	190	17%	110	11%	1300	11%
Off-Road Vehicles[2]	33	10%	--	--	--	--
Marketing Operations[2]	3	7%	--	--	--	--
Total	236	15%	110	11%	1300	11%

Source: California Air Resources Board. October 17, 1994. *Memorandum.*, "Phase 2 Reformulated Gasoline Emission Benefits." Peter D. Venturini to K.D. Drachand and Terry McGuire.
1. Derived from EMFAC7F.1/BURDEN7F1.1.
2. Derived from Predictive Emissions Inventory for 1990 base year.

D. Fuel System Components Potentially Sensitive to Fuel Composition

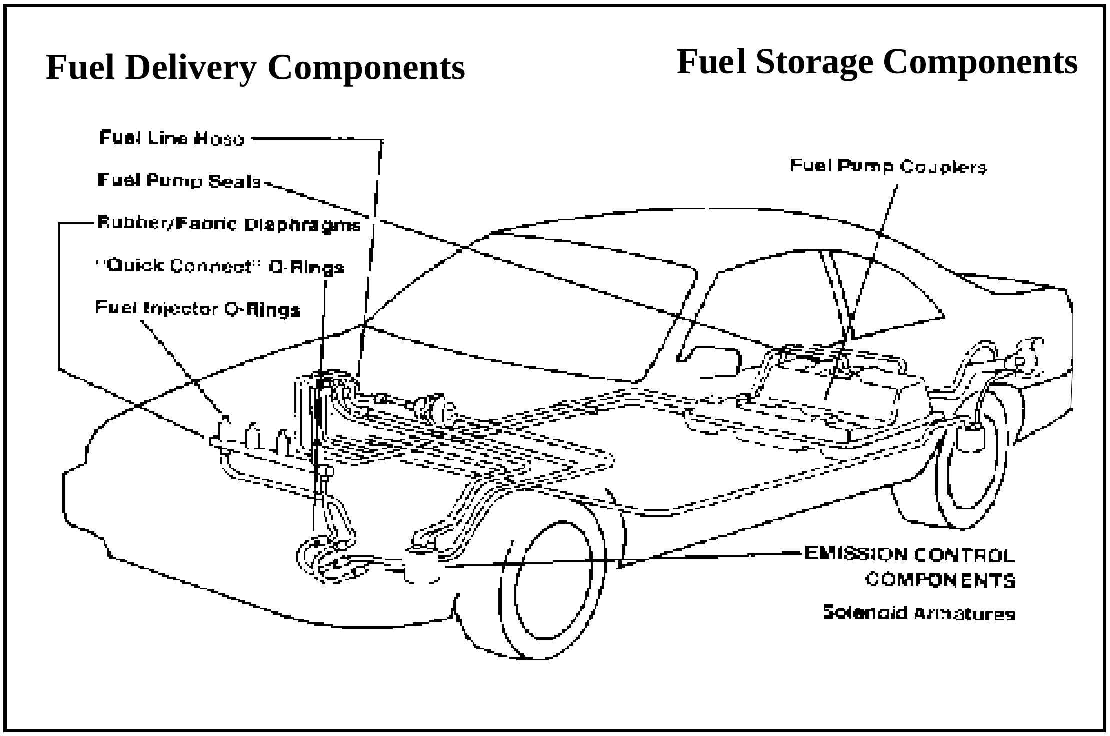
Fuel system components in motor vehicles consist of a wide variety of materials which can be generally grouped as elastomers, metals, and composites.

1. Elastomers

The elastomers used in motor vehicle fuel systems are made from compounds such as acrylonitrile, nitrile butyl rubber, epichlorohydrin copolymer, and fluoroelastomers (DuPont VITON). For example, fuel line hoses, fuel pump seals, and fuel injector o-rings are made from these compounds. Figure 1 shows where polymers may come in contact with gasoline in a typical gasoline-powered vehicle. (See Appendix 8 for more information on elastomers.)

The oxygenate and the lower aromatic content of CaRFG could have effects on some elastomers in some motor vehicle components. (See Appendix 9 for more information on effects of oxygenates on elastomers and Appendix 10 for more information the effects of aromatic content on elastomers). Oxygenated compounds and aromatic compounds may cause swelling of elastomer components and may degrade the elastomer properties. However, the lower aromatic content of CaRFG should decrease the tendency of the fuel to cause swelling and degrade elastomer components. The net result is expected to be only a small effect on elastomers, if any. Components made from materials such as nitrile butyl rubber and epichlorohydrin copolymer elastomers may experience more changes in swell characteristics when exposed to different fuels. Tests by DuPont indicate that the nitrile butyl rubber and epichlorohydrin copolymer elastomers can be adversely affected in a short period of time as compared to the fluorocarbon type of elastomers. Fluorocarbon elastomers have not been shown to be affected by these chemical changes.

Figure 1
Fuel System Elastomer Components



DuPont 1993. An update report on VITON in Automotive Fuel Systems. Wilmington, Delaware.

Seals and Hoses. Seals and hoses are normally used in fuel lines, fuel pumps, regulators, injectors, carburetors, and other automotive parts. Most seals and hoses are made from elastomers. Many fuel system hoses consist of a combination of materials (see Figure 2).

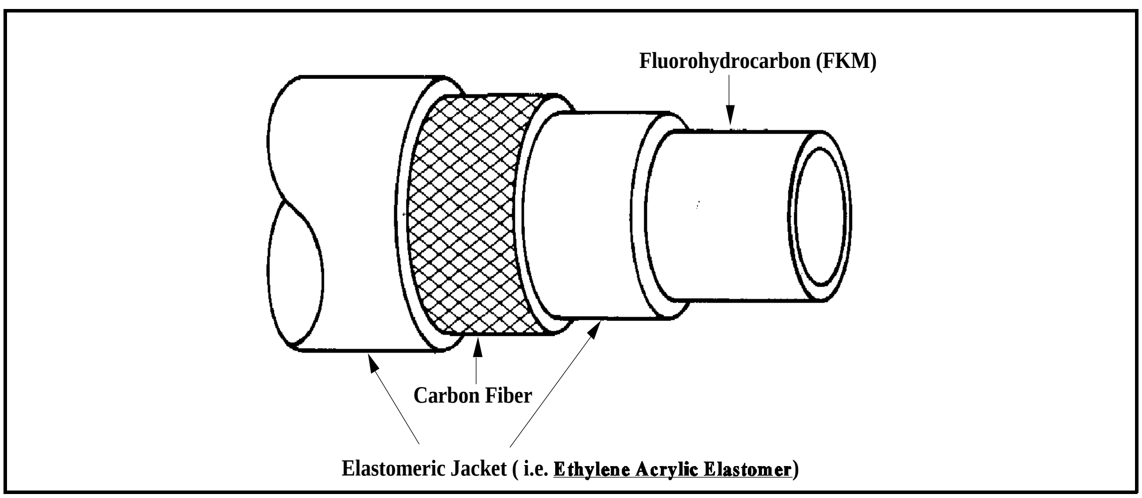
2. Metal and Composite Components

In a fuel system, the metal and composite components are fuel tanks, pumps, lines, regulators, injectors, and carburetors. Composite materials consist of at least 2 physically different materials, which are tightly bound together, as in fiberglass. The combination of the composite materials incorporates the properties of the different materials. Thus, composites can be designed for specific uses for fuel system components.

Several factors can affect the operation of metals and composites such as the age of the component, the corrosive nature of the fuel, a reaction between elements in the metal or composite and fuel, or any combination of these factors.

Engine parts are mostly metal although composite materials are used as well. When the fuel and metals interact, problems can occur with the engine parts because of the lubricity characteristics of the fuel which can potentially cause increases in wear of engine components. The lubricity characteristics potentially affect fuel pumps and fuel intake system components including injectors. (See Appendix 11 for more infomation on the lubricity characteristics of gasoline). However, since the middle of the 1980's, automobile manufacturers have, for the most part, designed fuel components and engines to be compatible with oxygenated gasolines with up to 10 percent ethanol or 15 percent methyl tertiary butylether (MTBE).

Figure 2
Fuel Hose Cutaway View



DuPont 1993. *An update report on VITON in Automotive Fuel Systems.* Wilmington, Delaware.

Sulfur compounds in gasoline may affect the metal, elastomer, and composite components in the fuel system, depending on the amount of sulfur in the fuel. On the one hand, reducing sulfur compounds in fuels will help prevent the corrosion of the metal and composite components or elastomer. In addition, it will help to reduce wear of engine components, deterioration of engine oil, and corrosion of exhaust system parts. On the other hand, reducing the sulfur compounds too much may adversely affect the metal components of the fuel system by reducing the lubricity characteristics of the fuel. The presence of oxygenates in the fuel can also affect lubricity characteristics (See the Final *Report of the Diesel Fuel Task Force* for more information).

E. Design of Fuel System Materials for Compatibility

Historically, some changes in motor vehicle fuels have necessitated a corresponding change in the fuel system materials so that they remain compatible with the fuels. For example, in the early 1980's, alcohols and ethers were introduced in fuels, requiring changes in some materials used for seals, hoses, and fuel tanks. Because of this evolution, fuel systems in newer vehicles are compatible with oxygenated gasolines that comply with the CaRFG regulations. (See Appendix 12 for more information on the design of fuel system materials for compatibility.)

Post-1985 vehicles. This era of vehicles signifies the departure from carbureted motor vehicles. Thus, almost all of these vehicles are fuel injected, and the fuel systems are designed to be compatible with ethanol-blended and MTBE blended fuels. The elastomeric components in these vehicles are, for the most part, made of fluoroelastomers. Also, some vehicles, such as flexible fuel vehicles, have components that may be compatible with high concentration methanol or ethanol fuel blends which are more corrosive than conventional gasoline.

1980-1985 vehicles. In the late 1970's, gasohol was introduced to the gasoline market. Gasohol is a combination of 10 volume percent ethanol (an oxygenate) and gasoline. In 1980-1985 vehicles, many vehicles and their original fuel system components, hoses and seals, were designed to be compatible with oxygenated fuels, like CaRFG.

Fuel hoses in many of these vehicles are made up of nitrile butyl rubber with a liner made of fluoroelastomers. These fuel hoses were introduced into the market in 1979. The fluoroelastomer-lined types were used in 1982 model year or newer vehicles made in the United States. Most European manufacturers of fuel injection systems used nylon tubing instead of rubber hoses..

Pre-1980 vehicles. The pre-1980 original components were generally not designed for gasohol compatibility. Almost all carburetors of pre-1980 vehicles have metal and nitrile butyl rubber fuel system components. However, in pre-1980 vehicles, many original components have been replaced with parts which are generally designed for gasohol compatibility. In addition, since 1992, these components have already been exposed to oxygenates, including primarily MTBE and ethanol, because oxygen is required in reformulated wintertime gasoline during the winter months in California.

F. Driveability

"Driveability" refers to the performance of the vehicle, with respect to ease of starting, smooth idling, acceleration, and lack of stalling. Some properties of gasoline are known to affect driveability. Vehicle driveability correlates with the driveability index (DI) shown in equation (1) and is a function of the fuel's distillation temperatures.

(1) DI = 1.5 *[T10] + 3.0 * [T50] +[T90]

Within limits, lowering the driveability index of the fuel, improves the driveability of vehicles. Because the CaRFG standards lower the maximum limits for T50 and T90, it is expected that CaRFG will provide better driveability than current conventional gasoline in vehicles (See the *California Phase 2 Reforumlated Gasoline Technical Support Document* for more discussion of driveability, RVP, and T50 and T90).

1. Reid Vapor Pressure

Reid vapor pressure is a measure of gasoline vapor pressure under specified conditions. Lower RVP would generally result in a higher T10 (front end volatility of gasoline) which will increase the DI and may lead to vehicle driveablity problems in some cases. Therefore, the T10 needs to be carefully adjusted to ensure adequate driveability. In California, gasoline is required to meet the American Society for Testing and Materials (ASTM) criteria, including the criteria for T10.

Also, if the RVP of the fuel is too low for the ambient temperature, a vehicle--especially an old vehicle--may not start easily. If the RVP of the fuel is too high for the ambient temperature or the carburetor temperature, a vehicle--especially an old vehicle--may suffer vapor lock. Vapor lock is a partial or complete interruption in the liquid flow of fuel because of excessive vaporization of the fuel. The CaRFG requirements lower the RVP specification to 7.0 pounds per square inch (psi) for summertime fuel. At this level, the gasoline volatility is expected to be adequate so that hard starting or vapor lock does not occur in motor vehicles.

2. T50 and T90

The T50 and T90 are distillation temperatures on the gasoline distillation curve as determined by the ASTM D 86 test. Specifically, T50 is the temperature at which 50 percent of the gasoline is evaporated, and T90 is the temperature at which 90 percent of the gasoline is evaporated. Both T50 and T90 are components of the DI equation and can affect vehicle driveability.

In general, low values of T50 have been related to good fuel economy in short trips, warm-up, and cool weather driveability. However, too low a value for T50 can result in hot start problems, vapor lock, and excessive evaporative emissions. Low values of T90 promote good driveability during longer trips in hot weather.

Compared to conventional gasoline, gasoline complying with the CaRFG standards, on average, will decrease T50 by about 12 degrees Fahrenheit and decrease T90 by about 40 degrees Fahrenheit. As a result, gasolines complying with the CaRFG standards are expected to provide better driveability, on average, than conventional gasolines.

G. Structure of the Report

The report is divided into three parts. Part One of this report covers the On-Road vehicle test program in the following chapters:

Chapter I describes the design of the On-Road vehicle test program.
Chapter II provides the description of the conduct of the On-Road vehicle test program.
Chapter III describes the sampling and analysis of fuels.
Chapter IV describes the data analysis of the On-Road vehicle test program.
Chapter V describes the baseline data.
Chapter VI provides the results of the On-Road vehicle test program.
Chapter VII discusses fuel economy of reformulated gasolines, in particular CaRFG.

Part Two of this report covers the industry-sponsored test programs in the following chapters:

Chapter I introduces the industry-sponsored test programs.
Chapter II discusses the Chevron U.S.A. Products Company test program.
Chapter III discusses the EMCO Wheaton and Dayco Products test programs.
Chapter IV discusses the Ford Motor Company lubricity test program.
Chapter V discusses the General Motors Company test program.
Chapter VI discusses the Harley-Davidson Motor Company test program.
Chapter VII discusses the Holley Performance Products test program
Chapter VIII discusses the Nissan Motor Company test program.
Chapter IX discusses the Texaco test program.
Chapter X discusses the United States Department of Energy test program.

Part Three of this report covers the off-road test program and manufacturers test program in the following chapters:

Chapter I introduces the off-road vehicles and equipment test program.
Chapter II discusses the utility, lawn, and garden test programs.

Chapter III discusses pleasure craft and small marine engines test programs.
Chapter IV discusses industrial, construction, and agricultural equipment test programs.
Chapter V discusses the personal watercraft test program.
Chapter VI discusses the snowmobile test program.

FINDINGS AND SUMMARY
OF THE CALIFORNIA REFORMULATED GASOLINE
TEST PROGRAMS

A. Introduction

A test program was conducted by the Air Resources Board (ARB) to evaluate the performance and compatibility of California Reformulated Gasoline (CaRFG) in on-road and off-road motor vehicles and gasoline burning equipment. This test program was designed and conducted with guidance and advice of the Performance Subcommittee of the California Reformulated Gasoline Advisory Committee. Members of the Subcommittee represent gasoline refiners, vehicle manufacturers, fleet managers, service station dealers, other industries and government agencies.

The On-Road test program lasted seven months, from February 1995 through August 1995. During this time, 829 vehicles accumulated over 5 million miles on CaRFG. An additional 637 vehicles were fueled with commercially available conventional gasoline and served as the control group. Eight private and government fleets participated in the test program. All of the 829 test vehicles burned the same CaRFG formulation representing what could be expected to typically be experienced by vehicles. The vehicles in the test program covered model years ranging from pre-1981 to current model year vehicles.

Table 3
Weight Class Comparison
On-Road Test Fleet and California Vehicle Population
(All Model Years)

Weight Class	On-Road Test Fleet Total All Years	California 1995 Vehicle Population Total All Years
Light-Duty Vehicles	47%	92%
Medium-/Heavy-Duty Trucks	53%	8%

Table 3 compares the vehicles in the test program with the vehicle population on the road in California. As indicated in the table, the 1995 California vehicle population consists of 92 percent passenger cars and light-duty trucks compared with the On-Road test fleet of 47 percent. In the medium-heavy-duty truck categories, the California vehicle population is 8 percent and the On-Road test population is 53 percent.

The On-Road vehicle test fleet and California vehicle population also differ in how the vehicles are maintained. In the On-Road test program, the vehicles are normally repaired and maintained on a regular basis by fleet mechanics. In addition, fleet mechanics tend to follow the manufacturer's recommended maintenance schedule. On the other hand, how private citizens maintain their vehicle can vary substantially. For instance, some repair their own vehicles while others have a professional mechanic repair their vehicle.

In addition to this test program, historical data from calendar years 1993 and 1994 were collected from over 7,000 vehicles from fleets operated by the same organizations that operated the fleets in the test program. These data were used to determine baseline fuel system component failure rates.

It was not possible to obtain a test fleet that exactly matched the distribution of the California vehicle population or to match the broad range of fuels that may be produced under the regulation. In addition, time constraints prevented long term evaluation of fuel effects. As a result, several supplemental programs were conducted by members of the Subcommittee to augment the data obtained from the fleet performance test program. These programs were conducted by Chevron, Texaco, General Motors, Ford, Nissan, Holley Performance Products, Harley-Davidson, and the United States Department of Energy.

The CaRFG test fuels used in the Chevron and Texaco vehicle test programs were not the same as the CaRFG test fuel used in the ARB 829 vehicle test program. The Chevron program involved the testing of 118 privately owned and operated employee vehicles with CaRFG and 117 privately owned and operated employee vehicles fueled with conventional gasoline. The Chevron program ran for 4.5 months. Texaco conducted two limited test programs to evaluate the performance of CaRFG fuels with very low levels of aromatics (5 to 10 percent by volume). The General Motors, Ford and Nissan programs were conducted to evaluate the effects of CaRFG fuels on fuel system elastomers and plastics, on deposit formation and on metal wear. The Harley-Davidson test program evaluated compatibility, durability, emissions and fuel economy in on-road motorcycles. The EMCO Wheaton, Incorporated and Dayco Products Incorporated sponsored testing on dispensing equipment. Holley Performance Products also tested CaRFG for compatibility with its products. The United States Department of Energy evaluated the long term effects of CaRFG on vehicles.

Off-road vehicles and equipment were tested in a wide variety of test programs to evaluate compatibility, performance and durability while using CaRFG. Off-road vehicles and equipment tests included lawn and garden equipment, marine engines, off-road vehicles and recreational equipment. These test programs ran from four to six months. The multiple design and usage characteristics of off-road vehicles, marine engines, and equipment made it necessary to develop several different test programs to cover a broad range of applications. In addition to field testing sponsored by ARB, several manufacturers of utility, lawn and garden equipment conducted laboratory and field testing which supplemented ARB’s data.

B. Findings from the On-Road Performance Test Program

- Results from the performance test program indicate that CaRFG performed as well as conventional fuel in terms of driveability, starting, idling, acceleration, power, and safety.

- Both the test and control fleets experienced similar fuel system problems on a small percentage (3 percent) of their vehicles. These included problems involving:
  - fuel pumps,
  - carburetors,
  - leakage in fuel hoses and various gaskets (seals), and
  - fuel tanks and tank components .

- Comparison of the overall problem frequency between the test and control fleets indicates that there is no meaningful difference between the frequency of problems in the fleets operated with CaRFG versus the fleets operated with pre-1996 (conventional) gasoline (See Table 4).

- Newer vehicles in the test and control fleets (1991 and newer) did not experience fuel system problems. The problems that occurred were seen in both the test and control fleets in older vehicles (pre-1991), generally with high mileages. The average model year of vehicles experiencing fuel system problems was 1986 and the average starting odometer reading was 95,000 miles with a range of 24,000 to 202,000 miles.

- Evaluation of the historical maintenance and repair data shows an increasing rate of failures in fuel system components associated with aging. The overall frequency of problems for both the test and control fleets (3 percent) is well below the expected frequency determined from the baseline historical data of 7,000 vehicles (10 percent) for equivalent time periods. The problems seen in the historical data are the same types as seen in the test and control vehicles.

- Evaluation of on-road fuel economy data indicates that use of CaRFG will reduce the average miles per gallon (fuel economy) by 1 to 3 percent. The 1 percent reduction results from comparing CaRFG to an oxygenated conventional gasoline; since oxygenates are already in widespread use in California, the 1 percent reduction is the expected average fuel economy change when CaRFG is introduced.

C. Findings from Industry Sponsored Test Programs

- The auto industry (GM, Ford) bench tests evaluated the effects of several CaRFG and conventional fuels on unused fuel system elastomers and plastics and on metal wear. The elastomer and plastic property changes and the metal wear rates observed in these studies are not expected to adversely affect fuel system performance in use.

- The Nissan test data indicate no adverse formation of deposits from use of CaRFG.

- The Harley-Davidson test program showed that the use of CaRFG in motorcycles caused no fuel system related problems.

- The Chevron employee fleet study was designed to complement the larger ARB fleet test program, with more emphasis on older, higher mileage and imported vehicles. Incorporating the Chevron data into the ARB test program data, does not change the findings described above, however, within the context of the Chevron test program, there were more incidents in the test fleet than the control fleet. The Chevron incident frequency rate is lower than the baseline failure rate that was found from ARB's review of the historical fleet repair records. The Chevron results are consistent with the results of the other test programs and review of repair records for vehicles operating on cleaner-burning gasoline and conventional gasolines, which indicates that older, higher mileage vehicles may have a higher risk of fuel system problems.

- The results of the two Texaco limited studies indicate that a switch from high to very low aromatic fuels might accelerate the failure of some fuel system components (e.g. seals and elastomers) in older, high mileage or extreme service vehicles. ARB independently evaluated proprietary refinery data and the California gasoline distribution system. This evaluation indicates that even if very low aromatic gasoline are produced, commingling in the distribution system and dilution in the vehicle tank should dampen gasoline property changes so that consumers should not experience property variations nearly as wide as those evaluated in the Texaco programs.

- EMCO Wheaton, Incorporated evaluated its A4000 series of fuel dispensing nozzles. Based on its test results, the EMCO Wheaton Company staff indicates that CaRFG is acceptable to use with its A4000 fuel dispensing nozzles.

- Dayco Products Incorporated evaluated gasoline dispensing hoses. They indicated that the results from the immersion tests on their hoses using the winter and summer fuels were satisfactory, and in some cases better than with some conventional gasolines presently in use.

- Holley Performance Products evaluated power valves and elastomer components used in carburetors. Holley Performance Products Company concluded: As a result of contact and operation tests, it has been found that California Reformulated Gasoline "... has no detrimental effect on Holley fuel handling products."

- United States Department of Energy evaluated the long term effect of cleaner burning gasoline on five vehicles. They did not report any compatibility problems. They also report a reduction in fuel economy which is consistent with the On-Road test program.

D. Results from Off-Road Performance Test Programs

- Review of data from all of the off-road test programs shows that the switch to, and the long term use of cleaner-burning gasoline is not expected to adversely affect off-road vehicles and equipment. No problems were experienced due to the use of CaRFG in these engines that could be linked to the fuel.

Table 4
California Reformulated Gasoline:
On-Road Test Program Data Analysis

		Test	Control
All Incidents	vehicles	829	637
	incidents	24	20
	percent	***2.9%***	***3.1%***
Fuel Pumps	vehicles	829	637
	incidents	12	6
	percent	***1.4%***	***0.9%***
Carburetors	vehicles	335	197
	incidents	8	7
	percent	***2.4%***	***3.6%***
Hoses	vehicles	829	637
	incidents	3	0
	percent	***0.4%***	***0.0%***
Seals	vehicles	829	637
	incidents	0	3
	percent	***0.0%***	***0.5%***
Tanks	vehicles	829	637
	incidents	0	4
	percent	***0.0%***	***0.6%***
"Other"	vehicles	829	637
	incidents	1	0
	percent	***0.1%***	***0.0%***

Source: California Air Resources Board. December 1, 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project* . Sacramento, California.

CHAPTER I

DESIGN OF THE
ON-ROAD TEST PROGRAM

A. Introduction and Objective

In this chapter, the design of the ARB On-Road test program is discussed, including a description of the test protocol, vehicle selection criteria, and test fuels. In designing the On-Road test program, the ARB staff relied upon the expertise and advice of the Subcommittee.

The primary objective of the On-Road test program is to evaluate the compatibility and performance of CaRFG with in-use vehicles and equipment compared with similar vehicles and equipment using conventional fuels.

The entire On-Road test program included 1466 vehicles, which are referred to as the "program fleet." The test program included 829 test vehicles and 637 control vehicles. In this report, "test vehicle" and "test fleet" mean vehicles that received the CaRFG test fuel. "Control vehicle" and "control fleet" refer to vehicles that received conventional fuel; and therefore these control vehicles received whatever commercially available gasolines their owners chose to buy.

B. Test Protocol

The Subcommittee developed a test protocol for the On-Road test program. This protocol documented the design and procedures for conducting the On-Road test program. The Committee endorsed the protocol in its final form. (See Appendix 1 for the Test Protocol for On-Road Test Program.)

The on-road protocol called for test fleets that represent the state's vehicle population. The Subcommittee wanted diverse fleets which included: (1) passenger cars, (2) light-duty trucks and vans, (3) medium-duty trucks, and (4) heavy-duty trucks and equipment. Further, the Subcommittee wanted to ensure that the composition of the test and control fleets were as similar as possible to each other in terms of vehicle characteristics and operating conditions.

C. Vehicle Selection

With a program of this magnitude, the Subcommittee agreed that the vehicle fleets needed to have the following characteristics:

- A centrally located fueling station for fleets to ensure that the test vehicles received test fuel only or at least received test fuel predominately.

- Uniform control to allow the ARB staff to maintain contact with the owner and the mechanic of each vehicle.
- A central location for the ARB staff to inspect vehicles periodically.
- Maintenance and fueling records.
- Available control fleets.
- A systematic way to record and receive the data to compute fuel economy for each test vehicle.

With the help of the National Association of Fleet Administrators, the ARB staff solicited various fleet operators in California to participate in the test program. The following 8 agencies agreed to participate in the On-Road vehicle test program:

- Bank of America
- California Department of Transportation
- City of Sacramento, Police Department
- County of Sacramento, General Services
- California State University, Fresno
- General Telephone & Electronics (GTE)
- Pacific Bell, Northern California
- Pacific Bell, Southern California.

Once a fleet owner agreed to participate, a Memorandum of Understanding (MOU) between the ARB and that fleet owner established the policies regarding the test program. Each MOU addressed the following:

- fuel supply
- data collection and reporting
- technical support
- performance evaluation
- program schedule
- duration

For each fleet, the MOU included the lists of the vehicles expected to participate in the test program and a test plan outlining the specific tasks of the fleet operator and ARB staff. (See Appendix 2 for copies of the MOUs)

1. Discussion of the Program Fleets

The fleets in the test program included a variety of vehicles that had been used in different types of service. The vehicles included all weight classes--light-, medium-, and heavy-duty. The fleets also included vehicles with a wide range of ages and model years.

By testing a wide range of vehicle types and a large number of vehicles, the effect of CaRFG on a wide range of fuel system components was investigated. By analyzing the data on a vehicle type by vehicle type basis, the data were extrapolated to most types of vehicles on the road--even though the relative numbers of vehicle types differed between the program fleets and the on-road population.

However, the Subcommittee recognized that these 8 fleets in the test program, with preventative maintenance programs and central fueling, might not typify the general vehicle population in California. In addition, although the program included a wide range of vehicles, the Subcommittee had concerns about the number of older vehicles. Further, concerns were raised about the lack of imported vehicles in the fleets; in addition, two of the program fleets did not have control vehicles (conventional fueled vehicles).

The Subcommittee addressed these concerns in two ways. First, the California State University, Fresno (CSU Fresno) fleet helped to address the concern of vehicle age. The CSU Fresno fleet had older vehicles, between 1964 to 1994. Second, because the vehicles needed to meet the selection criteria noted above, the On-Road program relied on commercial and government fleets, which seldom include imported vehicles. However, the representatives for Toyota Technical Center, U.S.A.; Nissan Research and Development; Mercedes-Benz of North America; and Mitsubishi Motors America, Inc. agreed that their technology would be adequately represented by the selected fleets. Also, the Chevron in-use test program addressed this limitation in part because it included employee vehicles, some of which were imported (See Part Two).

As noted, some participants in the program did not have control fleets. The control vehicles from the other fleets in the test program serve as the control comparison for the fleets without control vehicles. (Chapter II describes the On-Road fleets in more detail, and Chapter V describes the baseline data in more detail. For the off-road fleets, see Part Three.)

D. Description of Test Fuels

Based on the California refiners' confidential information, the ARB staff provided the Subcommittee with its estimate of what the average fuel properties may be in 1996. The Subcommittee established the test fuel specifications to resemble the typical values of complying CaRFG reaching the consumer.

To ensure that the test fuel is produced in a way typical of future CaRFG fuels, the Subcommittee established gasoline specifications for the blending materials that were used to produce the test fuel as well as compositional limits. This approach ensures that the test fuel is not only representative of future CaRFG but also is produced using the same refining processes and blended the same way as typical future CaRFG.

To address the seasonality of the RVP specification, the test program included a winter RVP specification and a summer RVP specification. For the sulfur specification, the Subcommittee recommended a limit below the average because most complying CaRFG fuels are expected to have sulfur contents below the average specification. For the aromatic hydrocarbon specification, the Subcommittee also recommended a specification range below the expected aromatic level because they were concerned that lower aromatic contents might affect fuel system components. The specifications for the test program fuel are shown in Table 5.

The ARB staff contracted with Phillips 66 Chemical Company to produce the test fuel given the 8 specifications decided on by the Subcommittee. Phillips 66 Chemical Company manufactured the test fuels at its refinery in Borger, Texas. To address the winter and summer RVP specifications, Phillips 66 Chemical Company blended a winter test fuel and a summer test fuel.

Table 5
Specifications for On-Road Test Fuel

	Winter	Summer
RVP, psi	11 to 12	6.5 to 6.9
Aromatic content, vol.%	18 to 20	18 to 20
Olefinic content, vol.%	3.0 to 5.0	3.0 to 5.0
Sulfur content, ppm	15 to 25	15 to 25
Benzene content, vol.%	0.5 to 1.0	0.5 to 1.0
Oxygen content[1], wt.%	~2	~2
T50, °F	190 to 210	190 to 210
T90, °F	280 to 300	280 to 300

1. To be provided as MTBE at 10.8 to 11.2 volume percent.

In addition to the limits in Table 5, Phillips 66 Chemical Company was given the following specifications:

- An Octane number ([R+M]/2) -- 88 to 90
- Standards for gasoline in American Society of Testing and Materials (ASTM) D 4814-93
- A deposit-control package to comply with section 2257 of the California Code of Regulations

Because the expected average octane number is about 89 for all gallons in 1996, the Subcommittee specified the range for octane number at 88-90, (R+M)/2.

Phillips 66 Chemical Company was also given the allowable ranges for blending materials or refinery process products shown in Table 6 for the composition of the test gasolines. As with the specifications, the Subcommittee set the range for the blending materials within limits that they expect will typify complying CaRFG. In trial blends that approximated the final product, Phillips 66 Chemical Company demonstrated that gasoline blended according to Table 6 meets the test fuel specifications in Table 5. (See Appendix 3 for Chemical and Physical Properties of CaRFG Test Fuel.)

Table 6
Limits on Test Fuel Composition by Blending Material

Blendstock Component	**Range**
Reformate, vol.%	20 to 30
MTBE, vol.%	10.8 to 11.2
Cracked stocks, FCC & hydro.	20 to 35
Alkylate, vol.%	15 to 20
Isomerate, vol.%	2 to 10
Straight-run naphtha, vol.%	as approved [1]
Other; as approved	as needed [2]

1. None was used by Phillips.
2. Butane was added to the winter test fuel.

CHAPTER II

DESCRIPTION OF THE ON-ROAD TEST PROGRAM

A. Introduction

This chapter explains how the On-Road test program was conducted, including the fuel delivery, vehicle fleets, and field activities.

B. Delivery of Test Fuel

Phillips 66 Chemical Company shipped test fuel from Texas by rail car to 2 rail terminals in California, 1 in Woodland and 1 in Wilmington. At these locations, the test fuel was loaded into a tank truck for delivery to the users. When the transition from winter to summer test fuel was scheduled to begin, the summer test fuel was not available, so Phillips shipped additional winter test fuel by truck from Texas to ensure that the test sites had test fuel. When the summer test fuel was available, Phillips 66 Chemical Company initially shipped the fuel by truck and then by rail.

A 9,000 gallon cargo tank truck was used for deliveries out of the rail cars to the fleet sites, except for CSU Fresno. For this site, the test fuel was delivered by a smaller truck with meters and pumps because this site had above ground tanks. (Note: the Lake Tahoe and Lake Cachuma off-road sites were also supplied by the smaller truck.) Before loading the test fuel, each compartment of both cargo tank trucks was drained and visually inspected.

The total deliveries to the test fuel sites were 159,000 gallons of winter test fuel and 393,000 gallons of summer test fuel (total of 552,000 gallons). The amounts delivered to each user and initial delivery dates are shown below in Table 7. (See Appendix 4 Test Fuel Deliveries to Fleet Sites) The deliveries of winter test fuel marked the beginning of the test program at each site. (Winter test fuel has a higher RVP than summer test fuel.)

At some sites, winter test fuel was not delivered until after the start of the low RVP season, which is during summer months. This was caused by unexpected delays in obtaining the test fuels from the Phillips 66 Chemical Company. To resolve this, an exemption from the low-RVP regulations was obtained to allow the test program to proceed. In addition, California in 1995 had a cooler spring than normal so that weather during this period was similar to winter conditions, minimizing any negative effects from using winter test fuel in the summer.

Before the first delivery of winter test fuel, the storage tanks at Bank of America, Caltrans, and Pacific Bell (both sites) were pumped out so that all vehicles were fueled with fully complying winter test fuel. At the other sites, the first winter test fuel was added to existing inventories; hence, the initial mix was at least half test fuel. During the transition to summer test fuel, the first delivery of summer test fuel was mixed with existing winter test fuel inventories, except at CSU Fresno where the tanks were empty. Thus, some transitions to both the winter and summer test fuels were abrupt, and some were gradual. This was done to simulate the real world transition to a new fuel.

Table 7
Test Fuel Deliveries During Test Program

	Winter Test Fuel		**Summer Test Fuel**	
	gallons	1st delivery	gallons	1st delivery
On-Road Sites				
Bank of America	9,928	Mar 1	9,515	May 1
Caltrans	26,306	Mar 2	38,103	May 16
City of Sacramento	41,026	Feb 27	114,877	Apr 14
County of Sacramento	12,894	Feb 27[1]	39,960	Apr 14[1]
CSU Fresno	0	--	21,673	May 12
GTE - Camarillo	29,210	Mar 3	75,788	Apr 18
Pacific Bell, North	19,098	Feb 28	54,733	Apr 14
Pacific Bell, South	14,670	Mar 1	24,615	Apr 10
Off-Road Sites				
Lake Tahoe	850	Apr 10	9,851	May 19
Lake Cachuma	0	--	3,572	Jul 25
Total	159,000		393,000	

Source: Air Resources Board 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project* . Sacramento, California.

1. Test fuel was delivered to two county sites. The dates shown here apply to the Branch Center Road site where about 90% of the test fuel used by county vehicles was provided.

For 7 of the 8 fleets, the test fuel was dispensed through early September 1995. The Bank of America test site had a mechanical problem with the storage tank's vapor recovery system that ended its participation in the test program on July 31, 1995.

C. Participating Fleets and Vehicles

Table 8 lists the participating fleet owners and the numbers of vehicles in each fleet. There were a total of 829 test vehicles and 637 control vehicles. Table 9 provides a summary of the all the vehicles in the On-Road test program by age, odometer, and weight class.

Table 8
On-Road Test and Control Fleet Populations

Participating Fleet	Test Vehicles	Control
Bank of America	20	10
Caltrans	25	0
City of Sacramento	106	81
County of Sacramento	173	241
CSU Fresno	112	0
GTE	254	157
Pacific Bell North	84	110
Pacific Bell South	55	38
Total	829	637

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.

Table 9
On-Road Test Program Vehicles Distribution by Model Year, Weight Class, and Odometer

Vehicle Category	Mileage (x1000)	Test				Control			
		<1981	1981-84	1985-89	>1989	<1981	1981-84	1985-89	>1989
Light Duty Vehicles	<50	3	8	24	103	2	7	33	105
	50-100	10	10	131	77	0	2	108	57
	>100-150	4	6	16	0	0	5	5	3
	>150	1	0	0	0	0	1	0	0
Medium Duty Vehicles	<50	8	0	74	45	1	2	49	30
	50-100	6	12	82	4	0	4	67	21
	>100-150	3	2	13	0	0	0	5	0
	>150	1	1	3	0	0	0	1	0
Heavy Duty Vehicles	<50	9	6	14	40	0	4	34	18
	50-100	10	22	35	5	1	7	40	7
	>100-150	6	16	9	1	0	9	7	2
	>150	5	2	2	0	0	0	0	0
Total		66	85	403	275	4	41	349	243

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.

Table 10 shows how these vehicles were distributed among model years and weight class, comparing an estimate of the percentage of On-Road test and control fleets with the percentage of the actual on-road fleet in California (See Appendix 5) Table 11 shows the distribution by odometer reading. (Appendix 6 also contains the site addresses and types of fuel dispensed.)

Table 12 shows the distribution of the program test fleets by model year for each fleet, demonstrating that the program test fleets have adequate numbers of vehicles in age groups back to pre-1981. The control fleet also covers all weight classes but includes few vehicles older than the 1981 model year. It should be noted that during the test program small changes occurred in some fleets due to the retirement of older vehicles, addition of new vehicles, relocation of vehicles, availability of vehicles for inspection, and vehicles not fueling at the test site. Tables 13 and 14 further summarize the characteristics of the individual fleets.

Table 10
Fleet Distribution by Model Year and Weight Class

Fleet	Weight Class [1]	<1981	1981-84	1985-89	>1989	Total
California Vehicle Population	**LDV**	11.5%	10.6%	27.4%	42.3%	**91.8%**
	MDT	0.8%	0.7%	1.5%	2.8%	**5.7%**
	HDT	0.5%	0.3%	0.7%	1.0%	**2.5%**
Subtotal		**12.7%**	**11.6%**	**29.6%**	**46.1%**	**100%**
On-Road Test Vehicles	**LDV**	2.2%	2.8%	20.4%	22.0%	**47.3%**
	MDT	2.2%	1.8%	20.9%	5.9%	**30.8%**
	HDT	3.6%	5.5%	7.2%	5.5%	**22.0%**
Subtotal		**8.0%**	**10.1%**	**48.5%**	**33.4%**	**100%**
On-Road Control Vehicles	**LDV**	0.5%	2.2%	22.9%	25.9%	**51.5%**
	MDT	0.2%	0.9%	19.2%	8.0%	**28.3%**
	HDT	0.2%	3.1%	12.7%	4.2%	**20.3%**
Subtotal		**0.8%**	**6.3%**	**54.8%**	**38.1%**	**100%**

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.

1. LDV = light-duty vehicles; MDT = medium-duty trucks; HDT = heavy-duty trucks.

Table 11
Distribution of On-Road Fleets by Odometer

(percent of each fleet)

	Test	Control	Calif. On-Road
<50,000 miles	40%	45%	31%
50,000 to 100,000	49%	49%	33%
>100,000 miles	11%	6%	36%
All	100%	100%	100%

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.

Table 12
Distribution of Vehicles by Model Year

Participating Fleet	Test or Control	Model Year				Total
		<1981	1981-1984	1985-1989	>1989	
Bank of America	Test	0	0	3	17	20
	Control	0	0	1	9	10
Caltrans	Test	5	7	4	9	25
	Control	-	-	-	-	-
City of Sacramento	Test	1	2	10	93	106
	Control	0	0	2	79	81
County of Sacramento	Test	0	6	96	71	173
	Control	0	2	153	86	241
CSU Fresno	Test	48	10	39	15	112
	Control	-	-	-	-	-
GTE	Test	8	52	161	33	254
	Control	0	29	98	30	157
Pacific Bell - North	Test	4	6	65	9	84
	Control	4	10	79	17	110
Pacific Bell - South	Test	0	2	25	28	55
	Control	0	0	16	22	38
Total	Test	66	85	403	275	829
	Control	4	41	349	243	637

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.

Table 13
Distribution of Vehicles by Weight Class

Participating Fleet	Test or Control	Vehicle Weight Class [1]			Total
		LDV	MDT	HDT	
Bank of America	Test	18	0	2	20
	Control	10	0	0	10
Caltrans	Test	3	1	21	25
	Control	-	-	-	-
City of Sacramento	Test	99	2	5	106
	Control	81	0	0	81
County of Sacramento	Test	128	20	25	173
	Control	162	42	37	241
CSU Fresno	Test	52	28	32	112
	Control	-	-	-	-
GTE	Test	91	103	60	254
	Control	55	60	42	157
Pacific Bell - North	Test	2	55	27	84
	Control	20	40	50	110
Pacific Bell - South	Test	0	45	10	55
	Control	0	38	0	38
Total	Test	393	254	182	829
	Control	328	180	129	637

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project* . Sacramento, California.
1. LDV=light-duty vehicles; MDT=medium-duty trucks; HDT=heavy-duty trucks.

Fleet Fueling Systems. The fleet owners used various mechanisms to ensure the exclusive use of test fuel in test vehicles. At Sacramento County and the Bank of America, under ordinary circumstances, test vehicles were fueled by electronic dispensers that allowed only test fuel to be delivered to the vehicles. With electronic fueling, the following information was obtained: vehicle identity, the date and time of fueling, and the volume of fuel dispensed. At the other test sites, only test fuel was available. The fleet owners were asked to inform the ARB of the test vehicles that were not available to continue participating in the test program or that received conventional fuel.

Table 14
Distribution of Vehicles by Odometer

Participating Fleet	Test or Control	Odometer Reading (x 1000)				Total
		<50	50 to 100	>100 to 150	>150	
Bank of America	Test	15	5	0	0	20
	Control	7	2	1	0	10
Caltrans	Test	11	4	4	6	25
	Control	-	-	-	-	-
City of Sacramento	Test	65	40	1	0	106
	Control	51	30	0	0	81
County of Sacramento	Test	40	129	4	0	173
	Control	94	140	7	0	241
CSU Fresno	Test	41	50	17	4	112
	Control	-	-	-	-	-
GTE	Test	96	123	35	0	254
	Control	92	52	13	0	157
Pacific Bell North	Test	19	46	14	5	84
	Control	23	70	15	2	110
Pacific Bell South	Test	47	7	1	0	55
	Control	17	21	0	0	38
Total	Test	334	404	76	15	829
	Control	284	315	36	2	637

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.

The sub-sections below provide narrative descriptions of the individual fleets.

1. Bank of America Fleet

The Bank of America fleet is primarily used as courier vehicles for the transfer of mail among the Bank of America facilities located in the Southern California area. These vehicles are driven in two separate shifts, morning and afternoon; between each shift, the vehicles are refueled. The fleet is located in the downtown Los Angeles metropolitan area.

The Bank of America fleet consisted of 20 test vehicles and 10 control vehicles, which were primarily selected to incorporate light-duty vehicles and passenger cars that operate under a heavy cyclic duty load. The test fleet consisted of 10 light-duty vans, 8 passenger cars, and 2 heavy-duty vans. The control fleet consisted of 7 light-duty vans and 3 passenger cars that operated on local gasoline, which met the federal reformulated gasoline standards.

The odometers of the test and control fleet vehicles varied from about 7,800 miles to 101,000 miles, and the model years ranged from 1988 to 1995. Most of the vehicles in the test program were Chevrolet Astrovans while the remainder of the test and control vehicles were Ford Escorts, Dodge Omnis, Ford LTD Wagons, Chevrolet Cavaliers, or Dodge B350's. Table 15 lists the fleet distribution by model year, weight class, and odometer.

Table 15
Bank of America Fleet
Distribution by Model Year, Weight Class, and Odometer

Vehicle Category	Mileage (x1000)	Control				Test			
		<1981	1981-84	1985-89	>1989	<1981	1981-84	1985-89	>1989
Light Duty Vehicle	<50	0	0	0	7	0	0	0	13
	50-100	0	0	1	1	0	0	3	2
	>100-150	0	0	0	1	0	0	0	0
	>150	0	0	0	0	0	0	0	0
Medium Duty Vehicles	<50	0	0	0	0	0	0	0	0
	50-100	0	0	0	0	0	0	0	0
	>100-150	0	0	0	0	0	0	0	0
	>150	0	0	0	0	0	0	0	0
Heavy Duty Vehicles	<50	0	0	0	0	0	0	0	2
	50-100	0	0	0	0	0	0	0	0
	>100-150	0	0	0	0	0	0	0	0
	>150	0	0	0	0	0	0	0	0
Total		0	0	1	9	0	0	3	17

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

A fueling card system was used to fuel the Bank of America vehicles. During the test program, only the test vehicles were allowed to access the storage tank that contained test fuel. Because the storage tank was scheduled for preventative maintenance in late July 1995, test fuel was not delivered after July 30, 1995. Hence, the test program for the Bank of America fleet ended on July 30, 1995. (See Appendix 7 for more information on the Bank of America Test Program.)

2. California Department of Transportation Fleet

The Caltrans fleet was selected primarily to incorporate older, high mileage, heavy-duty vehicles into the On-Road test program. The on-road vehicles that participated in the study belong to the Caltrans maintenance and construction crews. Most of the vehicles in this test fleet were driven to and from their work site. For example, the test vehicles were used to control the flow of traffic and make repairs on the highway. The test fleet is located in the City of Commerce, in Southern California. In addition, this fleet also has some off-road equipment participating in the off-road test program (see Part Three).

The test fleet consisted of 25 test vehicles operating on test fuel: 21 heavy-duty vehicles, 3 light-duty vehicles, and 1 medium-duty vehicle. Table 16 lists the fleet distribution by model year, weight class, and odometer. The initial test fleet size in the MOU was 36 vehicles. However, the Caltrans removed some of their vehicles from the site in Commerce, California.

Table 16
California Department of Transportation Fleet
Distribution by Model Year, Weight Class, and Odometer

Vehicle Category	Mileage (x1000)	Test			
		<1981	1981-84	1985-89	>1989
Light Duty Vehicles	<50	0	0	0	2
	50-100	0	1	0	0
	>100-150	0	0	0	0
	>150	0	0	0	0
Medium Duty Vehicles	<50	0	0	1	0
	50-100	0	0	0	0
	>100-150	0	0	0	0
	>150	0	0	0	0
Heavy Duty Vehicles	<50	0	1	0	7
	50-100	1	1	1	0
	>100-150	1	2	1	0
	>150	3	2	1	0
Total		5	7	4	9

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

The Caltrans odometers readings varied from about 2,900 miles to over 233,000 miles, with model years from 1973 to 1994, and included vehicles such as General Motors Corporation, Ford, Dodge, and International Harvester Company.

The Caltrans fleet drivers also completed a log for fueling each vehicle. The Caltrans maintains an extensive computer database that includes maintenance records for their entire fleet. (See Appendix 8 for more information on the Caltrans Test Program.)

3. City of Sacramento Police Fleet

The City of Sacramento police vehicles were selected because they undergo rigorous use. These vehicles are used a minimum of 10 hours a day with long idle times and frequent high speed vehicle pursuits. The test and control vehicles were located at two different sites in Sacramento: the Kinney site and Rooney site, respectively. Both are owned and operated by the City of Sacramento Police Department. To ensure performance and reliability, the vehicles are routinely inspected and receive preventive maintenance by in-house staff mechanics, as appropriate.

The City of Sacramento police fleet test program included 106 test vehicles and 81 control vehicles. In the initial MOU, the City of Sacramento identified 257 vehicles in the City of Sacramento fleet that could participate in the test program. However, some vehicles were removed from service while other vehicles were reassigned to different locations, thus reducing the number of vehicles in both the test and control fleets.

In the City of Sacramento Police fleets, over 90 percent of the vehicles were 1990 models or newer, with the remaining 10 percent between 1981 and 1989. The odometer readings ranged from about 100 to 100,000 miles. Table 17 lists the fleet distribution by model year, weight class, and odometer.

Vehicle fueling was controlled through an electronic cardlock system that maintained fueling records for each test and control vehicle. All test vehicles were assigned to the Kinney site where they received test fuel and routine maintenance. All control vehicles were assigned to the Rooney site where they received the control fuel and routine maintenance. (See Appendix 9 for more information on the City of Sacramento Police Test Program.)

Table 17
City of Sacramento Fleet
Distribution by Model Year, Weight Class, and Odometer

Vehicle Category	Mileage (x1000)	Control				Test			
		<1981	1981-84	1985-89	>1989	<1981	1981-84	1985-89	>1989
Light Duty Vehicles	<50	0	0	0	51	0	0	0	59
	50-100	0	0	2	28	0	0	7	32
	>100-150	0	0	0	0	0	0	1	0
	>150	0	0	0	0	0	0	0	0
Medium Duty Vehicles	<50	0	0	0	0	0	0	1	0
	50-100	0	0	0	0	0	1	0	0
	>100-150	0	0	0	0	0	0	0	0
	>150	0	0	0	0	0	0	0	0
Heavy Duty Vehicles	<50	0	0	0	0	1	0	0	4
	50-100	0	0	0	0	0	0	0	0
	>100-150	0	0	0	0	0	0	0	0
	>150	0	0	0	0	0	0	0	0
Total		0	0	2	79	1	1	9	95

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

4. County of Sacramento Fleet

The County of Sacramento vehicles were primarily passenger cars, vans, and light duty trucks with model years ranging from 1983 to 1994. The test vehicles were located at 2 different locations and included pool and individual vehicles from most of the county's departments.

The County of Sacramento fleet consisted of 173 test vehicles and 241 control vehicles, which were selected from a General Services fleet of approximately 2,000 vehicles. Prior to the start of the test program, the drivers of 277 test vehicles identified in the MOU were asked to be part of the test program. However, some of these vehicles were not included in the test program. Table 18 lists the fleet distribution by model year, weight class, and odometer.

The county maintenance records were used to obtain data on the vehicles for documentation and analytical purposes. The County of Sacramento provided a description of their maintenance program and how it fulfilled the inspection criteria for this program (See Appendix 10, "Letter from County of Sacramento," August 3, 1995.)

Table 18
County of Sacramento Fleet
Distribution by Model Year, Weight Class, and Odometer

Vehicle Category	Mileage (x1000)	Control				Test			
		<1981	1981-84	1985-89	>1989	<1981	1981-84	1985-89	>1989
Light Duty Vehicles	<50	0	0	21	42	0	0	11	20
	50-100	0	0	73	23	0	0	58	38
	>100-150	0	0	1	2	0	0	1	0
	>150	0	0	0	0	0	0	0	0
Medium Duty Vehicles	<50	0	1	9	4	0	0	2	2
	50-100	0	1	20	7	0	1	9	4
	>100-150	0	0	0	0	0	0	2	0
	>150	0	0	0	0	0	0	0	0
Heavy Duty Vehicles	<50	0	0	14	3	0	0	1	4
	50-100	0	0	13	3	0	5	12	2
	>100-150	0	0	2	2	0	0	0	1
	>150	0	0	0	0	0	0	0	0
Total		0	2	153	86	0	6	96	71

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

The County of Sacramento fleet received its fuel through electronically encoded keys. Test vehicles had access to the test fuel dispensers only while control vehicles had access to control fuel dispensers only. (See Appendix11 for more information on the County of Sacramento Test Program.)

5. California State University, Fresno Fleet

At CSU Fresno, the vehicles are used in a low-mileage utility setting, making short trips throughout campus several times a day; they are not normally driven off-campus. The CSU Fresno on-road fleet was particularly helpful for evaluating the test fuel because of the predominance of older vehicles in the fleet. The oldest vehicle in the fleet was a 1964 model.

The test fleet consisted of a total of 112 vehicles. However, because there was only one fueling station, the CSU Fresno test program did not have a control fleet. In the MOU, 120 vehicles were identified for testing. During the initial inspection, 8 vehicles listed in the MOU were found to be diesel vehicles; thus, the number of test vehicles was reduced to 112.

For the CSU Fresno fleet, the model years ranged between 1964 and 1995. The odometer readings also varied, between 50,000 to over 150,000 miles. Although most of the vehicles were light-duty trucks, medium-duty trucks and vans, and heavy-duty trucks were included. Table 19 lists the fleet distribution by model year, weight class, and odometer. (See Appendix 12 for more information on the CSU Fresno Test Program.)

Table 19
CSU Fresno Fleet
Distribution by Model Year, Weight Class, and Odometer

Vehicle Category	Mileage (x1000)	Test			
		<1981	1981-84	1985-89	>1989
Light Duty Vehicles	<50	3	1	8	7
	50-100	10	1	13	2
	>100-150	4	1	1	0
	>150	1	0	0	0
Medium Duty Vehicles	<50	8	0	2	2
	50-100	5	3	4	0
	>100-150	2	1	0	0
	>150	1	0	0	0
Heavy Duty Vehicles	<50	5	0	1	4
	50-100	5	2	5	0
	>100-150	3	1	4	0
	>150	1	0	1	0
Total		48	10	39	15

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

Testing at the CSU Fresno started May 12, 1995, significantly later than other on-road test programs, because of difficulties with the Fresno fuel storage and dispensing facility. As a result, the CSU Fresno fleet received only summer test fuel. Testing continued through August 31, 1995, for a total of nearly 4 months. The fueling records indicate that test vehicles were fueled consistently from the campus fueling facility. (See Appendix 12 for more information on the CSU Fresno Test Program.)

6. General Telephone & Equipment Fleet

The General Telephone & Equipment program fleet is primarily used for servicing and maintaining telephone systems and infrastructure. The General Telephone & Equipment test fleet was located in Camarillo, California; the control fleet was located in San Fernando, California.

Both fleets were similar in terms of the percentages of light-, medium-, and heavy-duty vehicles. In addition, both fleets had a few low-mileage, low-use cars and trucks. Although both fleets were similar, the test fleet had a higher number of older, higher mileage vehicles than the control vehicle fleet. The test fleet was 254 vehicles; the control fleet was 157 vehicles. Table 20 lists the fleet distribution by model year, weight class, and odometer.

Table 20
General Telephone & Electronics Fleet
Distribution by Model Year, Weight Class, and Odometer

Vehicle Category	Mileage (x1000)	Control				Test			
		<1981	1981-84	1985-89	>1989	<1981	1981-84	1985-89	>1989
Light Duty Vehicles	<50	0	5	9	5	0	6	4	4
	50-100	0	1	25	5	0	8	47	3
	>100-150	0	2	3	0	0	5	13	0
	>150	0	0	0	0	0	0	0	0
Medium Duty Vehicles	<50	0	1	33	10	0	0	42	13
	50-100	0	3	12	0	0	6	39	0
	>100-150	0	0	0	1	1	1	2	0
	>150	0	0	0	0	0	0	0	0
Heavy Duty Vehicles	<50	0	4	16	9	3	5	7	12
	50-100	0	5	0	0	4	9	6	1
	>100-150	0	8	0	0	0	12	1	0
	>150	0	0	0	0	0	0	0	0
Total		0	29	98	30	8	52	161	33

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

The General Telephone & Electronics fleet had some unique characteristics. Initially, the MOU listed 360 test vehicles and 234 control. After the first inspection, some vehicles remained on-site and others were not available for several reasons: some were sold, some transferred to other sites, and some located at satellite facilities.

For the first five months of the program, approximately 160 test vehicles and 102 control vehicles were identified as participating in the program. However, during a routine inspection in July 1995, an additional 94 vehicles were identified which were fueled with the test fuel from the beginning of the program. Further, an additional 55 vehicles were identified in the control fleet.

The fueling was conducted on site at the General Telephone & Electronics facilities, with each vehicle fueled nightly. Although the test fleet vehicles were fueled with test fuel every night, there was a possibility that a vehicle needed to be fueled with conventional fuel while in the field. However, the fueling records indicate that this seldom occurred. (See Appendix 13 for more information on the General Telephone & Electronics Test Program.)

7. Northern California Pacific Bell Fleet

The Northern California Pacific Bell fleet consisted primarily of light- and medium-duty utility vans and heavy-duty trucks which are used in servicing and maintaining telephone systems and infrastructure. Many of the vehicles in this fleet have on-board generators and auxiliary equipment, such as booms and pole diggers, that burn fuel while the engine is idling at the work site. Therefore, most of the vehicles in this fleet have longer idling times than normal.

The Northern California Pacific Bell fleet comprised 84 test vehicles and 110 control vehicles at various sites around Sacramento. In the actual test program, the number of vehicles in the fleet was very similar to the number of vehicles included in the MOU, 72 test vehicles and 107 control vehicles. The differences in number of vehicles were due to some changes in the vehicle fleet, with more vehicles available for inspection than originally anticipated. Table 21 lists the fleet distribution by model year, weight class, and odometer.

The test and control fleets were similar in composition. Most vehicles were in the 1985-1989 model years, and a majority of the vehicles had odometer readings between 50,000 to 100,000 miles. Test and control vehicles were fueled at separate sites. However, the sites did not have an electronic fueling system. (See Appendix 14 for more information on the Pacific Bell Test Program, Northern.)

Table 21
Northern Pacific Bell Fleet
Distribution by Model Year, Weight Class, and Odometer

Vehicle Category	Mileage (x1000)	Control				Test			
		<1981	1981-84	1985-89	>1989	<1981	1981-84	1985-89	>1989
Light Duty Vehicles	<50	2	2	2	0	0	0	0	0
	50-100	0	1	8	0	0	0	2	0
	>100-150	0	3	1	0	0	0	0	0
	>150	0	1	0	0	0	0	0	0
Medium Duty Vehicles	<50	1	0	4	2	0	0	9	4
	50-100	0	0	22	5	1	1	28	0
	>100-150	0	0	5	0	0	0	8	0
	>150	0	0	1	0	0	1	3	0
Heavy Duty Vehicles	<50	0	0	4	6	0	0	2	4
	50-100	1	2	27	4	0	3	10	1
	>100-150	0	1	5	0	2	1	3	0
	>150	0	0	0	0	1	0	0	0
Total		4	10	79	17	4	6	65	9

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

8. Southern California Pacific Bell Fleet

The Southern California Pacific Bell fleet is primarily used for daily maintenance and repair of telecommunication systems. Many of these vehicles also have a generator on-board that burns fuel from the vehicle's fuel tank while the engine is idling at the work site. The test fleet was located in the City of Commerce, south of Los Angeles, and the control fleet was located in the City of Laguna Niguel, near San Juan Capistrano.

This test fleet consisted of 55 vehicles that were primarily medium-duty vehicles. Over 90 percent of the fleet were vans--45 medium-duty and 6 heavy-duty, along with 4 heavy-duty trucks. In the MOU, the initial size was 73 test vehicles, compared with the final fleet size of 55 test vehicles. The Southern California Pacific Bell control fleet consisted of 38 vehicles which were primarily medium-duty vehicles. These included 35 Dodge vans and 3 GMC vans. The initial control fleet size listed in the MOU was 86 vehicles as compared with a final fleet size of 38 control vehicles.

In the Southern California test fleet, the vehicles varied in mileage from 8,500 miles to over 108,000 miles. The model years of these vehicles varied from 1984 to 1994. For the control fleet, the vehicle odometer readings ranged between 12,000 to 87,000 miles, and the model years varied from 1987 to 1994. Table 22 lists the fleet distribution by model year, weight class, and odometer. (See Appendix 15 for more information on the Pacific Bell Test Program, Southern.)

The vehicle fueling was electronically controlled for both test and control fleets.

Table 22
Southern Pacific Bell Fleet
Distribution by Model Year, Weight Class, and Odometer

Vehicle Category	Mileage (x1000)	Control				Test			
		<1981	1981-84	1985-89	>1989	<1981	1981-84	1985-89	>1989
Light Duty Vehicles	<50	0	0	0	0	0	0	0	0
	50-100	0	0	0	0	0	0	0	0
	>100-150	0	0	0	0	0	0	0	0
	>150	0	0	0	0	0	0	0	0
Medium Duty Vehicles	<50	0	0	3	14	0	0	17	24
	50-100	0	0	13	8	0	0	3	0
	>100-150	0	0	0	0	0	0	1	0
	>150	0	0	0	0	0	0	0	0
Heavy Duty Vehicles	<50	0	0	0	0	0	0	3	3
	50-100	0	0	0	0	0	2	1	1
	>100-150	0	0	0	0	0	0	0	0
	>150	0	0	0	0	0	0	0	0
Total		0	0	16	22	0	2	25	28

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

D. Field Activities

1. Field Data Logs

The Subcommittee designed three data sheets to gather information about the vehicles and their response to the test and control fuel. These were the "Vehicle Description Logs," the "Fuel System Inspection Logs," and the "Driveability/Incident Logs." Respectively, these were the source documents for the electronic database on vehicle characteristics, inspections of the fuel systems for leaks, and repair incidents to fuel systems. (See Appendix 16 for the Field Data Logs.)

2. Vehicle Description Logs

Most of the vehicle description logs were completed at their initial inspection site visit or when vehicles were added to the program. However, some vehicles turned out to be unavailable for inspection at the first pre-test inspection visit to a site. Hence, some description and initial inspection logs were completed late while other description logs were completed from the owner's records rather than visual inspection. Additional fuel system logs were to be filled out for all vehicles every two months.

3. Fuel System Inspection Logs

All fuel system components were inspected visually according to the fuel system inspection protocol. The first inspections began in late January 1995, and the final inspections were completed at the end of August 1995. In the interim, periodic inspections were conducted on as many vehicles as were available during the visits.

Because of logistical problems, however, not all of the vehicles received their initial inspections before the first use of test fuel at a site. Some of the logistical problems included unavailable ignition keys, home storage, drivers' work shift schedules, especially among police vehicles, the widespread geographical area to cover, and the re-assignments of vehicles to other sites. Thus, some vehicles were not inspected. For these vehicles, the information was obtained from the vehicle maintenance records and the fleet maintenance personnel.

4. Driveability/Incident Logs

The fleet maintenance personnel were instructed to complete the driveability/incident logs when a vehicle's fuel system was repaired or a driveability problem was noted; either event was called an "incident." The maintenance personnel were asked to save the failed parts for the technical review panel or the manufacturer to examine.

To ensure that adequate data were collected for evaluation, frequent telephone calls and on-site visits were initiated to review the progress of the testing, investigate recently encountered incidents, and assist the site staff in preparing driveability/incident logs. At times, technical representatives of vehicle manufacturers assisted. By reviewing the maintenance records, all relevant incidents were recorded in the program.

5. Emission Inspections

Originally, the Subcommittee intended that each vehicle undergo a pre- and post-test Bureau of Automotive Repair-90 Smog Check. However, upon inspection at the first program fleet, a BAR-90 Smog Check on each vehicle was considered an unnecessary expense to the fleet owners, especially when smog check records could be retrieved electronically from the Bureau of Automotive Repair. The ARB staff is continuing to work with the Bureau of Automotive Repair Smog Check Program to obtain these records.

CHAPTER III

SAMPLING AND ANALYSIS OF FUELS

A. Introduction

This chapter discusses the sampling protocol for the test and control fuels, the analytical methods and results, and quality control of the data. The goal of the sampling and analysis is to evaluate the properties of the fuels used at the test and control sites.

B. Gasoline Sampling Protocols

For each sampling schedule, fuel sampling protocols were designed to monitor the fuel actually delivered to the test vehicles. Throughout the test program, test and control fuel (conventional gasoline) samples were obtained for analyses from various points in the test program distribution system: the rail cars, cargo tank truck, storage tanks, and vehicle tanks.

1. Sampling Procedure

Three main sampling procedures were chosen: (1) the bottle sampling procedure, (2) the nozzle sampling procedure, and (3) a sampling procedure for fleet operators. The bottle sampling procedure was used to obtain samples of fuel from the rail cars and the cargo tank trucks and is specified in Title 13, California Code of Regulations (CCR), Section 2296. To obtain samples for the RVP analysis, the nozzle sampling procedure was used, which is also specified in Title 13, CCR, Section 2296.

Fleet operators obtained samples using the Reformulated Gasoline Test Program Sampling Procedure, which is similar to the nozzle sampling procedure but without the use of a nozzle extension and an ice water bath (See Appendix 17 for the Reformulated Gasoline Test Program Sampling Procedure.)

Typically, 2 samples in 1-liter containers, with locking screw top caps, were used for all samples. For tracking purposes, the sample containers were labeled in the following manner:

- sample number
- fleet name
- date the sample was obtained
- type of fuel ("CaRFG" or "conventional")

2. Sampling Schedules

Rail Cars and Cargo Tank Truck. The test fuel was sampled from each rail car before fuel was dispensed to the cargo tank truck. To determine the octane rating, test fuel from the rail cars was sampled once for the winter test fuel and twice for the summer test fuel using the bottle sampling procedure. The cargo tank truck was sampled once each day that the test fuel was delivered to a test site.

Additionally, samples were obtained once per month from the rail cars and shipped to Chevron and Shell for analyses in parallel with the ARB's analyses. These samples were shipped according to the requirements of the Department of Transportation, the International Air Transport Association, and United Nations International Civil Aviation Organization packaging specifications.

Test Site Storage Tank--Initial Sample. Prior to the first delivery of test fuel, the fuel from the storage tank at each test site was sampled. The purpose was to determine the characteristics of the fuel in the tank before the test fuel was added. The analyses of the conventional gasoline being used at each test site prior to the beginning of the test period are listed in Table 23.

Table 23
Test Site Conventional Fuel Analysis [1]
Immediately Prior to the Test

	Bank of America	Caltrans	City of Sacramento	County of Sacramento	GTE	Pacific Bell North	Pacific Bell South
Aromatics, vol%	15	21	24	24	27	26	23
Benzene, vol%	0.7	0.8	1.1	1.2	0.8	1.0	0.9
Olefins, vol%	6.1	8.3	10.2	10.4	5.9	8.6	8.9
Oxygen, wt%	2.0	2.2	0.2	1.9	2.2	0.5	1.9
RVP, psi	9.7	11.6	10.9	11.7	--	10.6	9.5
Sulfur, ppmw	112	157	134	158	101	124	147
T50, ºF	208	188	199	184	205	202	193
T90, ºF	331	335	330	336	334	331	328

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.

1. CSU Fresno - No conventional fuel data. New tank installed at this site prior to the beginning of the test.

Test Site Storage Tank--Routine Samples. At each test site, the fuel in the storage tanks was sampled routinely, about a day before receiving a delivery of test fuel, and about a day after receiving the test fuel. By sampling before and after, it was possible to monitor the fuel that went into the test vehicles and to detect inappropriate fuel in the test fuel tanks. Sampling at this same frequency was performed at each test site for each delivery of fuel.

Control Site Storage Tank--Routine Samples. At each control site, the fuel in the storage tanks was sampled in the same manner as the routine samples for the test site storage; however, there were some exceptions to the frequency of sampling. For example, if the control site routinely received deliveries of conventional gasoline more frequently than the test fuel, the operators were instructed to sample at the same rate as samples were taken for the test fuel.

Vehicle Tanks--Samples. When an incident was reported, an attempt was made to obtain a sample from the vehicle. These samples were typically 500 milliliters or less.

C. Analytical Methods

The ARB's Monitoring Laboratory Division (MLD) was the primary laboratory for testing the samples, but they contracted to Schwartz Oil Company, Incorporated to do some tests that they were not able to perform. Table 24 shows the test methods used by the laboratories.

When the samples arrived at the MLD in El Monte, California, they were logged-in according to the MLD standard operating procedures (Appendix 18, Standard Operation Procedures and Quality Control Procedures for Fuel Samples). One of 2 containers remained with MLD laboratory, and the other was sent to Schwartz Oil Company, Incorporated.

Approximately 450 samples of fuel were taken from the facility storage tanks at both test and control sites and were subsequently analyzed. In addition, samples were analyzed from some of the vehicle tanks with reported incidents. The samples were tested for the following physical and chemical properties listed in Table 24 below. (See Appendix 19 for the references to the test methods, American Society for Testing and Materials.)

Table 24
Fuel Analysis by Test Methods and Laboratories

Specification	Test Method	Laboratory
CaRFG Specifications		
Aromatics	D-5580	ARB/MLD
Benzene	D-5580	ARB/MLD
Olefins	D-1319	CORE Laboratories
Oxygen	D-4815	ARB/MLD
Sulfur	D-2622	EHL
T50	D-86	ARB/MSD
T90	D-86	ARB/MSD
RVP	D-5191	ARB/MSD
ASTM Specification, D4814-93a		
Water Tolerance	D-4814 A.3	CORE Laboratories
Copper Corrosion	D-130	CORE Laboratories
Vapor/Liquid Ratio	D-5188	CORE Laboratories
Oxidation Stability	D-525	CORE Laboratories
Appearance	Visual	CORE Laboratories
Existent Gum	D-381	CORE Laboratories
Miscellaneous		
Specific Gravity	D-1298	CORE Laboratories
Hydrocarbon Analysis	DHA	ARB/MLD

"D-" Designations refer to ASTM test procedures. Latest year of revision will be used.
DHA - Detailed Hydrocarbon Analysis (Neil Johansen & Associates.)
EHL - Environmental Health Laboratory under existing contract to ARB.
ARB/MSD - Mobile Source Division of the Air Resources Board.
ARB/MLD - Monitoring and Laboratory Division of the Air Resources Board.

(For the CaRFG specifications and blending material compositions, Chapter I, Tables 5 and 6.)

Table 25 lists the ASTM specifications for gasoline. These specifications applied to both CaRFG and conventional samples.

Table 25
ASTM Gasoline Specifications

Fuel Property	Specification
Distillation Endpoint	437 °F max
Distillation Residue	2 vol % max
Vapor / Liquid Ratio, Winter	124 °F min[1]
Vapor / Liquid Ratio, Summer	140 °F min[1]
Oxidation Stability	240 minutes
Copper Corrosion	1A
Existent Gum	5 mg/100 ml max
Water Tolerance	-7 °F max[1]

Source: American Society for Testing and Materials, 1993. *ASTM D4814-93a*.

1. Specification varies by region and month; value is the most restrictive in California.

D. Sampling Data

Table 26 shows the Phillips 66 Chemical Company and MLD's analytical results. Phillips 66 Chemical Company tested its fuel before the product was shipped by rail car. Both the Phillips Chemical Company and MLD's analyses show that winter test fuel met the designated test fuel specifications, except for the olefin content and T90. These two specifications were slightly high for the test fuel specifications; however, they still met the CaRFG specifications.

For the summer test fuel, the Phillips 66 Chemical Company's analysis shows that the test fuel design specification was exceeded for sulfur. The MLD summer test fuel analyses also show that the designed sulfur test specification was exceeded, and the designed olefin test fuel specification was exceeded slightly. However, the analytical results do not differ by more than the test method reproducibilities from the design values. Also, although the contract specifications were exceeded, the CaRFG specifications were not.

The rail car and tank truck samples were tested for compliance with the requirements in ASTM D4814. All the samples passed the specified test methods and quantitative standards.

The range of the control fuel properties are listed in Table 27 for the control sites. Samples of fuels at the control sites were analyzed for the 8 specifications. Table 27 shows the results of analysis for each site. As the table demonstrates, the fleet operators used conventional gasoline throughout the test program.

Table 26
Analytical Results for Test Fuels Before Deliveries to Test Sites

	Phillips Analysis	ARB Analysis[1]			Test Fuel Design Specifications
		Number of Samples	Mean	Standard Deviation	
Winter Test Fuel					
RVP, psi	11.2	0	--	--	11-12
Aromatics, vol%	18.7	23	19.9	0.6	18-20
Olefins, vol%	4.7	23	5.6	0.6	3.0-5.0
Sulfur, ppm	16.4	21	21	4	15-25
Benzene, vol%	0.67	23	0.6	0.02	0.5-1.0
MTBE, vol%	11.2	24	11.1	0.2	10.8-11.2
Oxygen, wt%	--	24	2.03	0.04	~2
T50, ºF	190	16	191	1.4	190-210
T90, ºF	300	17	303	2.3	280-300
Summer Test Fuel					
RVP, psi	6.99	28	6.6	0.1	6.5-6.9
Aromatics, vol%	19.8	48	18.4	0.5	18-20
Olefins, vol%	4.4	48	5.7	1.0	3.0-5.0
Sulfur, ppm	45	48	52	7	15-25
Benzene, vol%	0.95	48	0.89	0.06	0.5-1.0
MTBE, vol%	11.2	48	11.5	0.5	10.8-11.2
Oxygen, wt%	--	48	2.09	0.09	~2
T50, ºF	189	48	190	1.8	190-210
T90, ºF	297	48	298	2.5	280-300

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.

1. Number of data excluded as inconsistent with duplicate data or as outliers for the winter test fuel samples are: T50--2; T90--1; benzene--1; aromatics--1 sulfur--3

Table 27
Range of Gasoline Analyses at Control Sites

	Bank of America	City of Sacramento	County of Sacramento	GTE	Pacific Bell North	Pacific Bell South
Aromatics, vol%	25.7-32.4	26.9-38.9	22.5-39.5	23.6-26.1	26.4-36.5	21.1-25.2
Benzene, vol%	0.61-0.83	1.08-3.51	1.13-2.06	0.58-0.87	0.91-1.79	0.48-0.76
Olefins, vol%	7.6-14.5	4.5-16.2	6.3-14.6	7.6-11.0	4.0-13.1	5.8-9.8
Oxygen, wt%	1.86-2.12	0.02-0.35	0.02-0.71	1.65-2.02	0.91-1.79	1.56-2.12
RVP, psi[1]	NA	NA	NA	NA	NA	NA
Sulfur, ppmw	142-204	61-227	75-207	128-217	97-168	107-156
T50, ºF	204-218	187-229	182-229	198-213	204-218	193-213
T90, ºF	326-340	308-350	318-349	334-351	322-343	318-346

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.
1. RVP analyses were not made for the conventional gasoline samples.

During the test program, some duplicate samples were sent to Shell Oil Company and Chevron Research and Technology Company to compare their laboratory results with MLD laboratory results. Chevron received samples of winter time fuel only, while Shell received samples of summer time fuel only. Shell split its samples into three parts for triplicate analyses at three labs.

Table 28 shows the inter-laboratory comparison of fuel samples. The results for the labs were similar to each other, but the ARB test results were consistently lower than Shell's for RVP, T50, T90, and oxygen and higher for aromatics. (See Appendix 20, Fuel Sample Results for Chevron Research and Technology Company and Shell Oil Products.)

Table 28
Inter-Lab Comparison of Analyses [1]

Sample	Lab	RVP (psi)	T50 (°F)	T90 (°F)	Sulfur (ppm)	Oxygen (wt%)	Benzene (vol%)	Aromatics (vol%)	Olefins (vol%)
CSKE032	**MLD**	6.63	190	295	56	2.04	.89	18.3	7.2
(test site)	**Shell**	6.72	191	302	50	2.15	.92	17.8	6.0
	Shell	6.68	192	300	--	2.10	.87	17.9	8.3
	Shell	6.60	196	303	30, 90	2.16	.90	--	--
CSKE027	**MLD**	6.69	189	295	52	2.04	.89	18.1	5.7
(test site)	**Shell**	6.87	190	299	47	2.16	.91	16.8	6.2
	Shell	6.77	191	298	--	2.11	.86	15.9	7.6
	Shell	6.76	193	305	34, 86	2.18	.89	--	--
CSKE036	**MLD**	--	194	301	52	2.17	.90	18.4	7.3
(test site)	**Shell**	6.76	193	306	51	2.18	.91	17.2	6.2
	Shell	6.76	190	301	--	2.12	.84	17.0	6.9
	Shell	6.64	194	305	36, 91	2.18	.90	--	--
CSK 017	**MLD**	6.89	189	298	50	2.11	.87	18.3	8.3
(test site)	**Shell**	7.02	190	300	43	2.17	.91	17.7	5.4
	Shell	6.89	191	297	34	2.13	.85	--	--
	Shell	6.96	192	302	79	--	.86	--	--
CSKA001	**MLD**	10.9	190	300	43	2.09	.62	24.0	11.8
(test site)	**Chevron**	11.0	190	300	18	--	.62	22.5	9.7

Source: Air Resources Board 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.
1. Test methods were not always consistent among the labs.

Table 29 shows the arithmetic means of the ARB's analyses of samples taken from the users' storage tanks throughout the periods following the initial deliveries of winter test fuel and summer test fuel. As noted previously, a sample was taken from a tank within 1 day before each delivery of test fuel and within 1 day after each delivery. (Appendix 21 shows more statistics on the analytical results of the CaRFG Test Fuel.)

In general, the analyses of the tank samples are consistent with the analytical results in Table 26. However, there are some exceptions. First, some conventional fuels were added to the fuel tank at one of the Branch Center sites, Sacramento County, and Tahoe Winter Sports, an off-road testing participant. Second, the results are generally inconsistent on olefin content between the tank samples and the product analyses. The olefin differences varied among the test sites throughout the program; however, this variability is within the expected reproducibility of the olefin test method.

Table 29
Average Results for Analyses of Fuels at Test Sites
(over all samples, except for RVP)

Test Program Site	RVP (psi)	T50 (°F)	T90 (°F)	Oxygen (wt%)	Benzene (vol%)	Aromatic (vol%)	Sulfur (vol%)	Olefin (vol%)
Winter Test Period								
Bank of America	---	190	305	2.09	.62	19.6	23	6.8
Caltrans	---	189	301	2.07	.61	19.9	21	6.0
City of Sacramento	10.85	188	303	2.10	.61	19.4	22	6.6
County of Sac.								
(Branch Center[1])	---	193	310	1.65	.95	22.5	49	6.9
(7th Street)	---	188	305	2.04	.67	17.3	34	6.4
CSU Fresno[2]	---	---	---	---	---	---	---	---
GTE	---	191	304	2.03	.63	20.1	32	5.1
Pacific Bell, North	---	191	304	1.97	.64	19.8	29	6.8
Pacific Bell, South	---	189	304	2.02	.61	19.3	25	5.7
Lake Cachuma[2]	---	---	---	---	---	---	---	---
Lake Tahoe[1]	---	195	306	1.88	.60	20.9	33	6.0
Summer Test Period								
Bank of America	---	192	301	2.09	.76	19.3	38	6.7
Caltrans	---	192	301	2.11	.85	18.3	53	5.3
City of Sacramento	6.71	190	298	2.11	.88	18.3	51	6.6
County of Sac.								
(Branch Center)	---	190	299	2.08	.86	18.4	50	6.0
(7th Street)	---	190	299	1.93	.70	19.5	35	6.7
CSU Fresno	---	189	297	2.09	.92	18.3	54	6.4
GTE	---	190	298	2.13	.89	18.4	50	6.1
Pacific Bell, North	6.68	190	299	2.10	.83	18.8	46	6.1
Pacific Bell, South	---	189	298	2.09	.82	18.6	45	5.6
Lake Cachuma	---	197	316	1.9	.88	20.3	74	5.1
Lake Tahoe[1]	---	196	311	1.90	.89	19.8	65	5.8

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

1. Some conventional fuel was received during the test period at this site.
2. No winter test fuel delivered to these sites.

At the County of Sacramento site on Branch Center Road, conventional gasoline was inadvertently delivered to the test fuel tank after the first delivery of winter test fuel. However, by April 13, 1995, after two more deliveries of test fuel, the measured fuel properties of the tank content were indistinguishable from the delivered test fuel. There were no other contaminations of the test fuel for the On-Road test program, except for the initial presence of pre-test fuels in some of the storage tanks, which was done to simulate the real world experience.

At sites where the majority of incidents occurred, the Division of Measurement Standards of the Department of Food and Agriculture sampled the fuels for possible fuel contamination. The samples were tested for sediment and water contamination at the test and control sites. No problems were identified. (See Appendix 22 for the analyses of these results.)

E. Quality Control

Upon arrival at the MLD, samples underwent a series of steps to ensure proper analysis and recording of results. The quality control procedures were followed throughout the program.

CHAPTER IV

DATA COLLECTION AND DATA ANALYSES

A. Introduction

This chapter discusses how the On-Road data were collected during the test program, how the technical review panel operated and how the data were analyzed. (Chapter V discusses baseline data in more detail, and Chapter VII discusses fuel economy.)

B. Description of On-Road Data

As described in Chapter II, data were collected on the 829 test vehicles and the 637 control vehicles using the following separate forms: (1) Vehicle Description Logs, (2) Fuel System Inspection Logs, and (3) Driveability/Incident Logs. The data were collected through initial inspections, bi-monthly inspections, and follow up investigations of incidents which were reported. Subsequently, the data were entered into an electronic database. To ensure accuracy, all the data underwent a data verification process. These data are stored at the Teale Data Center. (Appendix 23 Data Dictionary and Data Fields for ARB Database.)

1. Data from Vehicle Description Logs

At the beginning of the test program, the Vehicle Description Logs were filled out when the initial inspection of each vehicle participating in the test program occurred. Where the information could not be gathered directly from the vehicle, the data were obtained through other sources such as fleet maintenance records, the Department of Motor Vehicle registration records, and Smog Check Inspection data.

For the County of Sacramento, the fleet operators did their own inspections and filled out the vehicle description forms. All data were processed, underwent quality assurance steps, and were stored in the Vehicle Description file. The file contains 52 fields of information such as vehicle identification data, engine specifications, vehicle classification, fuel system information, smog equipment types, and odometer readings.

2. Data from Fuel System Inspection Logs

Twice a month, the test vehicles were visually inspected. During these inspections, a Fuel System Inspection Log was filled out for each vehicle inspected and the information was subsequently entered into the database. The data collected included: the odometer reading at the time of inspection, whether or not a vehicle fuel system component passed a visual inspection, and the degree to which a component's integrity had been compromised if it failed the inspection.

3. Data from Driveability and Incident Logs

In most cases, the incidents that occurred during the test program were reported via the Driveability/Incident Log. Some incidents were not reported on the driveability logs; however, they were recorded in the maintenance records. For these incidents, the driveability incident logs were filled out and reported to the technical review panel. The incident data were incorporated into the incident data files as part of the database. (No driveability problems were noted in the test program.)

Definition of Incident Data. The technical review panel provided expert guidance in defining an incident. In general, an "incident" means that the fuel system component identified was adjusted, repaired, or replaced in circumstances outside of the scheduled maintenance.

C. Technical Review of Incident Data

The Subcommittee established the technical review panel as a sub-group to review, evaluate, and render an expert opinion as to the nature of reported incidents. The technical review panel evaluated and classified all incidents, and some were classified as not being related to the fuel.

The technical review panel includes the following representatives:

- Bureau of Automotive Repair: Bob Benjaminson
- Chevron Research and Technology: Randy Barber and Kevin Carabell
- Texaco Refining and Marketing Incorporation: Peter Dorn and Mike Kulakowski
- Shell Oil Products: Tim Sprik and Larry Olejnik
- Exxon Research and Engineering Company: Albert Hochhauser
- Ford Motor Company: Dan DonLevy and Brian Rippon
- General Motors Corporation: Gerald J. Barnes
- GM Service Technology Group: Jim Trost, John Stott, and Alex Wong
- Chrysler Corporation: Loren K. Beard
- California Air Resources Board: Dean Simeroth, Paul Jacobs, Don Chernich, and John Courtis

1. Protocol for On-Road Test Program Incidents

The technical review panel developed a 3 letter coding scheme to characterize the reported incidents which is known as the incident "status code." The first letter of the status code identifies whether or not an incident was fuel related. The second letter identifies whether or not corrective actions were taken, and the third letter indicates whether or not the incident should be considered "normal" or "unusual," with respect to the age and mileage of the vehicle. (See Appendix 24 Materials Used by the Technical Review Panel to Determine Incidents. See Appendix 25 for Classification of Reported Incidents.)

After establishing the coding scheme, the technical review panel then reviewed each reported incident on a case-by-case basis. The evaluation included reviewing all background materials, which included, but were not limited to, fleet maintenance records, ARB bi-monthly inspection reports, relevant photographs, and component inspections. To augment these materials, the technical review panel also reviewed any failure analyses provided by original equipment manufacturers for some components. (See Appendix 26 for "Letter from Walter M. Kreucher to Dean C. Simeroth, November 6, 1995.) Based on the technical review panel's review, a status code was then assigned to each incident.

2. Review of On-Road Test Program Incidents

The technical review panel reviewed all the incidents reported. They classified each of the incidents as being related or unrelated to the fuel, and seeps were classified separately. The technical review panel did not find any incidents that could be directly attributed to the fuel used. Table 30 shows the number of incidents that were categorized as being fuel-related, not fuel-related, and seeps. Seeps are discussed below.

Table 30
Total Number of Incidents Reported

Category	**Test**		**Control**	
May be Fuel Related	24	2.9%	20	3.1%
Unrelated to the Fuel	8	0.9%	4	0.6%
Seeps [1]	86		28	
Total	118		52	

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project* . Sacramento, California.
1. Does not include 45 "test fleet" seeps and 17 "control fleet" seeps from the beginning of the test program.

Incidents Which "May be" Fuel Related. The technical review panel identified 44 incidents that may be fuel-related, 24 incidents from the 829 test vehicles and 20 incidents from the 637 control vehicles. Table 31 lists the incidents by the status code for both the test and control fleet. A MAN designation means May be fuel-related, Action taken, considered "Normal." A MAU designation means May be fuel-related, Action taken, considered Unusual. MNU means May be fuel-related, No action taken, considered Unusual. (See Appendix 27 for "Letter from Joe's Tire Center to Caltrans," August 11, 1995. See Appendix 28 for Letters on Test Fleet Incidents.)

Incidents Determined to be "Unrelated." The technical review panel identified 12 incidents, from both the test and control vehicles, that were unrelated to the fuel. These incidents included faulty electrical components, loose fuel fittings, and other miscellaneous incidents. These incidents were given a status code of unrelated to the fuel.

Table 31
Summary of Incidents by Code

Type	Test or Control	MAN	MAU	MNU	Total
Fuel Pump	Test	7	5	0	12
	Control	4	2	0	6
Carburetor	Test	3	5	0	8
	Control	3	4	0	7
Fuel Tank	Test	0	0	0	0
	Control	2	2	0	4
Fuel Hose	Test	1	2	0	3
	Control	0	0	0	0
Seal	Test	0	0	0	0
	Control	0	2	1	3
Other	Test	1	0	0	1
	Control	0	0	0	0
Total	Test	12	12	0	24
	Control	10	9	1	20

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project* . Sacramento, California.

3. Incidents Characterized as Seeps

During the test program, 131 seeps were reported on the test vehicles. Forty-five of these seeps were reported during the initial baseline inspections from test vehicles, and the remaining 86 seeps were identified during subsequent bi-monthly inspections; however, 47 of the 86 seeps were not reported again at the next inspection. In the control vehicles, 45 seeps were identified; 17 of these seeps were identified during the initial baseline inspections and 28 during subsequent bi-monthly inspections. For the control vehicles, only 4 seeps were reported again during the next inspection. (See Appendix 29 for a General Motors Company Letter, July 21, 1995.)

Definition of a Seep. A seep is a “wet” spot or a stain near a gasket, seal, or fitting which suggests that the fuel may have "seeped" from this area under operating conditions. As opposed to a drip or a leak, a seep will not have actual fuel which can be observed at the time of inspection (See Appendix 30 for “Letter from Mr. Loren K. Beard to Mr. Dean Simeroth,” November 1, 1995.)

To determine the exact nature of the seeps, the technical review panel formed a task group which included field representatives from General Motors Corporation, Chrysler, and Ford. This task group was chaired by Mr. Loren K. Beard of the Chrysler Corporation, a recognized expert in the field of automotive fuel systems. For this investigation, field inspectors from the task group examined a number of the seeps and photographed 16 vehicles. (See Appendix 31 for Initial Inspections of Seeps October 3, 1995. Appendix 32 for Bank of America Letter, July 13, 1995. Appendix 33 for Pictures of the Seeps. Apendix 34 for Followup Letters on Seeps.)

From their investigation, the task group concluded that all of the reported seeps should be characterized as a "normal" occurrence and not be attributed to the test fuel. Also, some of the seeps were determined to be from liquids other than gasoline such as coolants.

D. Data Analysis

This section discusses how the data from the test program were analyzed; the data from the incident records and the data from the historical maintenance records, referred to as baseline data, were also analyzed. The vehicle and incident data have been organized to allow comparisons between the rate of incidents in the test and control fleets. (See D. 1 below for more detail on the comparisons. Chapter V provides more detail on the baseline data.)

1. Groups of Vehicles

Selected groups of vehicles in the test fleet were identified along with corresponding groups in the control fleet. The rates of incidents for these groups of vehicles were compared. (See Appendix 35 for a complete listing of the comparisons.)

One group includes light-duty vehicles which are passenger cars and other vehicles that weighed less than 6,000 pounds gross weight, and another includes medium- and heavy-duty vehicles which are trucks and vans that weighed more than 6,000 pounds gross weight. Within these 2 groups and for each model year, the technology and materials used in the fuel system components are similar. Further, the vehicles within these 2 groups tend to be used for similar types of service.

The test and control rates were also compared for 4 groups of vehicles based on model year. The 4 model year groups are as follows:

- pre-1981
- 1981 through 1984
- 1985 through 1989
- post-1989

These model years roughly parallel the changes in technologies and materials used in the fuel systems of the test vehicles in the on road test program.

In addition, the test and control rates were compared for the following 3 groups based on odometer readings:

- Vehicles with less than 50,000 miles
- Vehicles with 50,000 to 100,000 miles
- Vehicles with more than 100,000 miles

The odometer groups roughly correspond to transitions in the useful life of fuel system components.

2. Types of Incidents

For each group of test and control vehicles described above, the rate of observed incidents were compared for some of the following types of incidents:

- All incidents of any type
- Fuel pump replacements
- Fuel line repairs
- Carburetor repairs, including elastomer seals
- Fuel injector repairs
- Fuel tank repairs including tanks, fill pipes and caps, and fuel-level sending units

These types of incidents correspond to the types of repairs included in the baseline data. (Appendix 35 Statistical Analysis of Incident Data.)

3. Comparison of Adjusted Rates of Incidents

To evaluate the effect of the fuels on incident rates, the observed rates were adjusted to compensate for differing proportions of weight classes, model years, and odometer readings in the test and control fleets. Using standard statistical test procedures the adjusted rates were compared for the corresponding groups of test and control vehicles. This method allowed the differences that may be fuel-related to be distinguished from those that were not. (For more details, see Appendix 36 Statistical Analysis of Baseline Data.)

CHAPTER V

BASELINE DATA

A. Introduction

To supplement the test program, the ARB staff collected historical maintenance data for various fleets. The objective is to establish a baseline incident rate prior to introducing CaRFG to the public.

As indicated in Chapter IV, the baseline data were used to estimate prevailing incident rates for fuel-related components and adjust the observed incident rates for the test and control fleets to compensate for differing proportions of vehicles by weight class, model year, and odometer reading.

In collecting the baseline data, the fleets that participated in the On-Road test program were targeted. In a parallel effort, the ARB staff continues to work on obtaining historical sales data on fuel system components. By obtaining sales information for replacement of defective fuel system components, the staff can attempt to confirm the incident rates which were observed in the baseline data.

Historical data were collected, processed, and evaluated from fleets operated by the same organizations that participated in the On-Road test vehicle program. The baseline data included maintenance and repair records for 1993 and 1994 on over 7,000 vehicles. For these 7,000 vehicles, more than 20,000 repair records were obtained on the fuel-related system components. The repair records were identified by vehicle manufacturer, model type, model year, and repair mileage. The frequency and repair rates for each individual fleet were determined as well as each fleet's overall repair rates.

B. Analysis of Baseline Data

The baseline data were analyzed to determine the rates of fuel system repairs in real-world situations. These repair rates provide an independent basis for evaluating the rates of repairs observed in the On-Road test fleets.

1. Determining Consistent Terminology

When the data were reviewed, different terms for similar repairs were identified. Similarly, certain fleets had more detailed records than others. As a result, a consistent set of codes to identify specific repairs were determined. These codes correspond to the types of repairs noted in the On-Road test program. The data from each fleet were translated to conform with these codes.

The following are the repair codes used for determining baseline incident rates:

- fuel pumps (FP)
- fuel injectors (FI)
- fuel lines (FL)
- fuel tanks (FT)
- carburetors (CA)
- fuel filter (FF)
- fuel system (FS)
- other (OT)

The last 3 repair codes--FF, FS, and OT-- represent common fuel system maintenance operations, which do not correspond to significant repairs in the test program. Consequently, these data were excluded from further analysis.

For each fleet that supplied historical repair data, the data also included some vehicles with repeated repairs within a year. To derive baseline rates comparable to the On-Road test program rates, each vehicle was limited to a single repair of a given type per year. For example, if the fleet records showed 3 carburetor repairs on an individual vehicle in 1993, only 1 of these repairs was recorded in determining a baseline rate for carburetor repairs.

2. Accounting for Differing Fleet Compositions

The vehicle fleets in the On-Road test program differed from the aggregate baseline fleets in terms of the weight classes, model years, and mileage of vehicles. As a result, these differences were further studied because the baseline data revealed that repair rates were not constant, but the repair rates varied according to a vehicle's weight class, (light-, medium-, or heavy-duty), model year, and mileage.

In general, the baseline data suggest that repair rates increase for older model years or higher mileage vehicles, or both. In addition, the repair rates increased from light- to medium- to heavy-duty. Therefore, a system was constructed that allowed the baseline information to be adapted to the specific population of vehicles for any given set of vehicles in the On-Road test program.

The baseline data were defined by combinations of the following criteria:

- Class of Vehicle
    - Light-Duty
    - Medium-Duty and Heavy-Duty

- Model Year
  - Before 1981
  - 1981 to 1984
  - 1985 to 1989
  - 1990 to present

- Odometer
  - Less than 50,000 miles
  - 50,000 to 100,000 miles
  - 100,001 to 150,000 miles
  - More than 150,000 miles

Table 32
Overall Baseline Data Distribution
by Mileage and Model Year
(In Vehicle-Years)

Vehicle Category	Mileage (x1000)	<1981	1981-84	1985-89	>1989	Total
Light Duty Vehicles	<50	49	31	636	2739	3455
	50-100	34	140	1582	1480	3236
	>100-150	7	64	957	80	1108
	>150	0	20	140	2	162
Light Duty Subtotal		90	255	3315	4301	7961
Medium Duty Vehicles	<50	8	14	253	1999	2274
	50-100	6	87	708	620	1421
	>100-150	5	91	601	56	753
	>150	2	33	151	4	190
Medium Duty Subtotal		21	225	1713	2679	4638
Heavy Duty Vehicles	<50	40	54	207	790	1091
	50-100	125	301	749	291	1466
	>100-150	155	374	540	41	1110
	>150	77	165	211	1	454
Heavy Duty Subtotal		397	894	1707	1123	4121
Total Vehicle-Years		508	1374	6735	8103	16720

Source: Air Resources Board. 1995. *Baseline Data : Reformulated Gasoline Project.* Sacramento, California.

A total of over 16,000 vehicle-years were used from historical data. Table 32 shows the complete distribution of the 1993-1994 baseline data according to vehicle-years by model year, odometer, and class of vehicle. Further, Tables 33 through 39 show the breakdown on a per fleet basis of the 1993-1994 baseline data.

The baseline data were analyzed using the 32 different combinations for the class, model year, and odometer of each vehicle. The data provided an empirical rate of repairs for each combination. (Appendix 36 contains a table of rates and vehicle counts for each combination and for each type of repair.)

3. Determining Baseline Repair Rates

The baseline data were used to determine the baseline rates that would be appropriate for each of the 32 combinations. These baseline rates were determined through a 2 step calculation.

For the first step, to calculate the empirical rate, the data specific to each combination were identified. Second, these rates were then adjusted to reflect the major trends among the 32 combinations relating to the effects of weight class, model year, and mileage on the rates. This adjustment produced the baseline incident rates for each combination and helped improve the statistical consistency in combinations where the data were relatively weak. (See Appendix 36 for more details on the estimation method.)

Table 33
Caltrans Baseline Data Distribution by Mileage and Model Year
(Vehicle-Years)

Vehicle Category	Mileage (x1000)	<1981	1981-84	1985-89	>1989	Total
Light Duty Vehicles	<50	1	0	57	1071	1129
	50-100	0	23	595	579	1197
	>100-150	1	18	663	40	722
	>150	0	11	98	0	109
Light Duty Subtotal		2	52	1413	1690	3157
Medium Duty Vehicles	<50	0	2	46	1424	1472
	50-100	2	21	422	480	925
	>100-150	3	46	501	46	596
	>150	2	19	111	2	134
Medium Duty Subtotal		7	88	1080	1952	3127
Heavy Duty Vehicles	<50	20	39	143	549	751
	50-100	91	267	634	240	1232
	>100-150	143	343	496	37	1019
	>150	71	161	199	1	432
Heavy Duty Subtotal		325	810	1472	827	3434
Total Vehicle-Years		334	950	3965	4469	9718

Source: Air Resources Board. 1995. *Baseline Data: Reformulated Gasoline Project.* Sacramento, California.

Table 34
City of Sacramento Baseline Data Distribution by Mileage and Model Year
(Vehicle-Years)

Vehicle Category	Mileage (x1000)	<1981	1981-84	1985-89	>1989	Total
Light Duty Vehicles	<50	0	4	216	545	765
	50-100	0	28	358	268	654
	>100-150	0	2	24	6	32
	>150	0	0	6	2	8
Light Duty Subtotal		0	34	604	821	1459
Medium Duty Vehicles	<50	2	2	77	223	304
	50-100	2	20	102	42	166
	>100-150	0	0	0	0	0
	>150	0	0	6	2	8
Medium Duty Subtotal		4	22	185	267	478
Heavy Duty Vehicles	<50	12	4	38	161	215
	50-100	20	14	48	34	116
	>100-150	2	6	10	2	20
	>150	0	2	6	0	8
Heavy Duty Subtotal		34	26	102	197	359
Total Vehicle-Years		38	82	891	1285	2296

Source: Air Resources Board. 1995. *Baseline Data : Reformulated Gasoline Project.* Sacramento, California.

Table 35
General Telephone & Electronics Baseline Data Distribution by Mileage and Model Year
(Vehicle-Years)

Vehicle Category	Mileage (x1000)	<1981	1981-84	1985-89	>1989	Total
Light Duty Vehicles	<50	0	13	181	39	233
	50-100	0	27	212	15	254
	>100-150	0	9	31	0	40
	>150	0	0	2	0	2
Light Duty Subtotal		0	49	426	54	529
Medium Duty Vehicles	<50	2	6	74	52	134
	50-100	0	24	25	2	51
	>100-150	0	13	3	0	16
	>150	0	2	2	0	4
Medium Duty Subtotal		2	45	104	54	205
Heavy Duty Vehicles	<50	6	11	8	22	47
	50-100	3	15	0	0	18
	>100-150	0	12	2	0	14
	>150	0	0	0	0	0
Heavy Duty Subtotal		9	38	10	22	79
Total Vehicle-Years		11	132	540	130	813

Source: Air Resources Board. 1995. *Baseline Data : Reformulated Gasoline Project.* Sacramento, California.

Table 36
CSU Fresno Baseline Data Distribution by Mileage and Model Year
(Vehicle-Years)

Vehicle Category	Mileage (x1000)	<1981	1981-84	1985-89	>1989	Total
Light Duty Vehicles	<50	32	0	22	16	70
	50-100	24	0	22	0	46
	>100-150	4	2	0	0	6
	>150	0	0	0	0	0
Light Duty Subtotal		60	2	44	16	122
Medium Duty Vehicles	<50	4	0	2	2	8
	50-100	2	0	4	2	8
	>100-150	0	4	0	0	4
	>150	0	0	0	0	0
Medium Duty Subtotal		6	4	6	4	20
Heavy Duty Vehicles	<50	0	0	0	0	0
	50-100	0	0	0	0	0
	>100-150	0	0	0	0	0
	>150	2	0	0	0	2
Heavy Duty Subtotal		2	0	0	0	2
Total Vehicle-Years		68	6	50	20	144

Source: Air Resources Board. 1995. *Baseline Data : Reformulated Gasoline Project.* Sacramento, California.

Table 37
Pacific Bell North Baseline Data Distribution by Mileage and Model Year
(Vehicle-Years)

Vehicle Category	Mileage (x1000)	<1981	1981-84	1985-89	>1989	Total
Light Duty Vehicles	<50	0	0	4	0	4
	50-100	0	0	9	0	9
	>100-150	0	5	5	0	10
	>150	0	1	0	0	1
Light Duty Subtotal		0	6	18	0	24
Medium Duty Vehicles	<50	0	0	16	8	24
	50-100	0	0	37	0	37
	>100-150	0	0	5	0	5
	>150	0	0	2	0	2
Medium Duty Subtotal		0	0	60	8	68
Heavy Duty Vehicles	<50	0	0	10	8	18
	50-100	3	1	41	1	46
	>100-150	0	7	12	0	19
	>150	0	0	0	0	0
Heavy Duty Subtotal		3	8	63	9	83
Total Vehicle-Years		3	14	141	17	175

Source: Air Resources Board. 1995. *Baseline Data: Reformulated Gasoline Project.* Sacramento, California.

Table 38
County of Sacramento Baseline Data Distribution by Mileage and Model Year
(Vehicle-Years)

Vehicle Category	Mileage (x1000)	<1981	1981-84	1985-89	>1989	Total
Light Duty Vehicles	<50	16	14	156	1068	1254
	50-100	10	62	386	618	1076
	>100-150	2	28	234	34	298
	>150	0	8	34	0	42
Light Duty Subtotal		28	112	810	1720	2670
Medium Duty Vehicles	<50	0	4	38	290	332
	50-100	0	22	118	94	234
	>100-150	2	28	92	10	132
	>150	0	12	30	0	42
Medium Duty Subtotal		2	66	278	394	740
Heavy Duty Vehicles	<50	2	0	8	50	60
	50-100	8	4	26	16	54
	>100-150	10	6	20	2	38
	>150	4	2	6	0	12
Heavy Duty Subtotal		24	12	60	68	164
Total Vehicle-Years		54	190	1148	2182	3574

Source: Air Resources Board. 1995. *Baseline Data : Reformulated Gasoline Project.* Sacramento, California.

4. Estimating Expected Repair Rates for Test and Control Fleets

To produce the "expected" incident rates, the baseline incident rates determined above were applied to the groups of test and control vehicles. This calculation involved 3 steps. First, the number of vehicles in a group was counted for each of the 32 combinations. Second, for each group, these counts were multiplied by their respective baseline incident rates to produce the expected number of repairs for each combination. Third, the expected repairs were summed to determine the overall incident repair rates, which were expected annually for each group.

This methodology allowed accounting for the differences in fleet composition between the test and control fleets. Table 39 shows the overall expected incident rates were about 8.3 percent for the test fleets and about 6.8 percent for the control fleets. These expected incident rates are based on a six month test period.

Table 39
Expected Incident Rates for On-Road Test and Control Fleets
(for six month test period)

Component Type	Test	Control
Fuel Pump	2.1%	1.7%
Fuel Lines	1.9%	1.6%
Carburetors	2.2%	1.5%
Fuel Injectors	0.7%	0.8%
Fuel Tanks	1.4%	1.2%
Overall	8.3%	6.8%

Source: Air Resources Board. *Baseline Data : Reformulated Gasoline Project.* Sacramento, California.

The expected rates, which were estimated with the baseline data, are systematically higher than the incidents rates that occurred in the On-Road vehicle test program. (See Table 41)

CHAPTER VI

RESULTS OF THE ON-ROAD TEST PROGRAM COMPATIBILITY AND DRIVEABILITY

A. Introduction

This chapter presents the results of the On-Road test program for compatibility and driveability, including a description and analysis of the observations during the On-Road test program.

B. Compatibility of Vehicles and Fuel

1. Overall Incidents in the Test and Control Fleets

Table 40 presents a comparison of incidents for the test and control fleets. Table 41 compares the observed rates of incidents with the expected rates of incidents for all fleets in the On-Road program. (The "rate" is defined as the number of incidents divided by the number of vehicles.)

Overall, there were 24 incidents in the test fleets and 20 incidents in the control fleets. This represents an observed rate of incidents of about 2.9 percent for the test fleet and about 3.1 percent for the control fleets. The overall observed rate for the control fleet is about the same as the rate for the test fleet. Further analyses of the differences in incident rates between the test and control fleets were conducted and it was found that none were statistically significant. (Table 40 shows the observed rates. See Appendix 35 for more details.)

Table 41 compares the observed and the expected incident rates side-by-side. The estimated expected incident rates are generally higher than the observed rates. It is not clear whether the observed rates should be higher or the expected rates should be lower. In some cases, the expected may include some routine maintenance and repairs which are not fuel-related. As a result, the agreement was much better for parts such as fuel pumps which do not have routine maintenance scheduled.

Table 40
Observed Incidents and Incident Rates [1]
in the On-Road Test Program

Incident Type	Test Fleet (829 vehicles)		Control Fleet (637 vehicles)	
	# Observed	Rate	# Observed	Rate
Light-Duty				
Fuel Pumps	4	1.0%	0	0.0%
Carburetors	1	0.3%	2	0.6%
Fuel Lines	0	0.0%	0	0.0%
Fuel Injectors	0	0.0%	0	0.0%
Fuel Tanks	0	0.0%	0	0.0%
Subtotal	5	1.3%	2	0.6%
Medium- & Heavy-Duty				
Fuel Pumps	8	1.8%	6	1.9%
Carburetors	7	1.6%	7	2.3%
Fuel Lines	3	0.7%	0	0.0%
Fuel Injectors	0	0.0%	0	0.0%
Fuel Tanks	0	0.0%	5	1.6%
Other	1	0.2%	0	0.0%
Subtotal	19	4.4%	18	5.8%
Total				
Fuel Pumps	12	1.4%	6	0.9%
Carburetors	8	1.0%	9	1.4%
Fuel Lines	3	0.4%	0	0.0%
Fuel Injectors	0	0.0%	0	0.0%
Fuel Tanks	0	0.0%	5	0.8%
Other	1	0.1%	0	0.0%
Total	24	2.9%	20	3.1%

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems/Reformulated Gasoline Project.* Sacramento, California.

1. The totals may not match perfectly because values are rounded to the nearest decimal.

Table 41
Observed and Expected Incident Rates [1]
for On-Road Test and Control Fleets

	Test Fleet		Control Fleet	
	Observed	"Expected"	Observed	"Expected"
Light-Duty				
Fuel Pumps	1.0%	1.0%	0.0%	0.8%
Carburetors	0.3%	0.8%	0.6%	0.5%
Fuel Lines	0.0%	0.8%	0.0%	0.7%
Fuel Injectors	0.0%	0.7%	0.0%	0.8%
Fuel Tanks	0.0%	0.5%	0.0%	0.5%
Overall	1.3%	3.8%	0.6%	3.3%
Medium- & Heavy-Duty				
Fuel Pumps	1.8%	3.1%	1.9%	2.6%
Carburetors	1.6%	3.5%	2.3%	2.6%
Fuel Lines	0.7%	2.9%	0.0%	2.5%
Fuel Injectors	0.0%	0.7%	0.0%	0.9%
Fuel Tanks	0.0%	2.3%	1.6%	1.9%
Overall	4.4%	12.4%	5.8%	10.5%
Total				
Fuel Pumps	1.4%	2.1%	0.9%	1.7%
Carburetors	1.0%	2.2%	1.4%	1.5%
Fuel Lines	0.4%	1.9%	0.0%	1.6%
Fuel Injectors	0.0%	0.7%	0.0%	0.8%
Fuel Tanks	0.0%	1.4%	0.8%	1.2%
Overall	2.9%	8.3%	3.1%	6.8%

Source: Air Resources Board. 1995. *Baseline: Reformulated Gasoline Project.* Sacramento, California.

1. Incidents of the "other" category were not included in the direct comparison.

Additional analysis was performed to "normalize" the incident rates to compensate for the differences between the test and control fleets, taking into consideration the baseline data. The results are shown in Table 42 below. The normalized incident rates form the basis for comparing the test and control fleet incident data.

Table 42 shows that there were some small differences in normalized incident rates between the test and control fleets in the On-Road test program. These differences were analyzed using standard statistical procedures. Overall, for the test and control vehicles, the analysis indicated that the differences between the normalized rates are not significant and should not be attributed to the differences in fuels used.

Table 42
Comparison of Normalized[1] Incident Rates For Test and Control Fleets in the On-Road Test Program

Incident Type	Test Fleet	Control Fleet
Light-Duty		
Fuel Pumps	1.0%	0.1%
Carburetors	0.3%	0.9%
Fuel Lines	0.0%	0.1%
Fuel Injectors	0.1%	0.0%
Fuel Tanks	0.0%	0.1%
Subtotal	1.3%	1.1%
Medium- & Heavy-Duty		
Fuel Pumps	1.8%	2.5%
Carburetors	1.6%	3.1%
Fuel Lines	0.7%	0.4%
Fuel Injectors	0.2%	0.0%
Fuel Tanks	0.0%	1.9%
Subtotal	4.4%	7.8%
Total		
Fuel Pumps	1.4%	1.4%
Carburetors	1.0%	2.1%
Fuel Lines	0.4%	0.3%
Fuel Injectors	0.1%	0.0%
Fuel Tanks	0.0%	1.0%
Total	2.9%	4.7%

Source: Air Resources Board. 1995. *Baseline Data : Reformulated Gasoline Project.* Sacramento, California.

1. Incidents of the "other" category were not included in the direct comparison.

C. Comparing the Incident Rates by Odometer Reading

The effects of mileage accumulation were evaluated. Table 43 shows the total incidents and fuel pump incidents by odometer for both test and control fleets. It shows, for both fleets, that the rate of incidents, whether observed or expected, increased with mileage. In both the test and control fleets, the vehicles with odometer readings greater than 100,000 miles experienced about 10 times higher observed incident rates when compared with the incidents from vehicles with less than 50,000 miles. In addition, the expected incident rates for vehicles with over 100,000 miles experienced 4 to 5 times more incidents than the vehicles with less than 50,000 miles.

Table 43
All Incidents and Fuel Pump Repair Rates by Odometer

Incident Type	Odometer (1000 mi.)	Test Vehicles			Control Vehicles		
		Incidents Observed	Observed Rate[1]	Expected Rate[1]	Incidents Observed	Observed Rate[1]	Expected Rate[1]
All Incidents	<50	4	1.2%	4.4%	3	1.1%	4.2%
	50 to 100	7	1.7%	9.1%	11	3.5%	7.9%
	>100	13	14.3%	18.9%	6	15.8%	16.1%
Fuel Pumps Replaced	<50	1	0.3%	1.0%	1	0.4%	0.9%
	50 to 100	3	0.7%	2.3%	2	0.6%	2.0%
	>100	8	8.8%	4.9%	3	7.9%	4.2%

Source: Air Resources Board. 1995. *Baseline Data: Reformulated Gasoline Project.* Sacramento, California.
1. Number of incidents/number of vehicles.

Table 44 shows the average odometer readings and ranges for all incidents in both test and control fleets in the On-Road test program. On average, for the test fleet, the incidents occurred at odometer readings of about 102,000 miles, with a range of 24,300 and 202,000 miles. For the control fleet, the incidents occurred at odometer readings of about 87,000 miles, with a range of 24,200 to 184,000. The overall average mileage for all incidents is about 95,000 miles, with a range of 24,000 to 202,000. Table 44 also shows that, on average, the incidents occurred at very similar odometer readings for the test and control fleets.

Table 44 also shows the average odometer readings for the entire fleet for both the test and control vehicles. For both the test and control fleets, the incidents occurred in vehicles with 30,000 to 40,000 miles higher than average miles, which is indicated by comparing the entire fleet average with the average mileage for the incidents. Thus, as in the baseline data, mileage seems to be an important factor in the occurrence of fuel system problems.

Table 44
Average Odometer Readings and Range for All Incidents

Incident Type	Test	Range	Control	Range	All	Range
Fuel Pump	108,000	24,300-202,000	107,000	35,700-184,000	107,000	24,300-202,000
Carburetor	87,800	39,400-160,000	76,100	24,200-132,000	82,300	24,200-160,000
Hose Leak	106,000	40,200-202,000	--	--	106,000	40,200-202,000
Seal Leak	--	--	76,600	67,600-91,900	76,600	67,600-91,900
Fuel Tank	--	--	81,800	33,700-139,000	81,800	33,700-139,000
Other	129,700	--	--	--	129,700	--
Average	102,000	24,300-202,000	86,600	24,200-184,000	94,900	24,200-202,000
On-Road Fleet[1]	**62,000**	**13-234,000**	**57,000**	**80-179,000**	**60,000**	**13-234,000**

Source: Air Resources Board. 1995. Air Resources Board. 1995 *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

1. Entire test program fleet at the beginning of the program.

D. Comparing Incident Rates by Model Years

Rates of incidents by fuel pump and all incidents were compared with the model years in Table 45. The most recent model year for which an incident was observed was 1990. No incidents were observed for 1991 or newer vehicles.

In general, older vehicles had higher rates of incidents. However, the observed incident rates for the pre-1981 vehicles were lower than the observed incident rates for the 1981 to 1984 vehicles. There appear to be 2 primary reasons for this. First, the sample size is relatively small. Second, the fuel system components in many pre-1981 vehicles have reached their expected service life and may have already been replaced with new fuel system components.

Table 45 also shows the expected incident rates for the model year groups. In almost all model year groups, the observed incident rates are lower than the expected incident rates. This appears in both test and control vehicle groups.

Table 45
All Incidents and Fuel Pumps by Model Year

Incident Type	Model Year	Test Vehicles			Control Vehicles		
		Incidents Observed	Observed Rate[1]	Expected Rate[1]	Incidents Observed	Observed Rate[1]	Expected Rate[1]
All Incidents	**pre-1981**	2	3.0%	19.8%	0	0%	11.8%
	1981-1984	4	4.7%	19.1%	5	12.2%	17.3%
	1985-1989	17	4.2%	8.1%	13	3.7%	8.5%
	post-1989[2]	1	0.4%	2.5%	2	0.8%	2.4%
Fuel Pumps Replaced	**pre-1981**	0	0%	4.8%	0	0%	2.7%
	1981-1984	2	2.4%	5.0%	2	4.9%	4.5%
	1985-1989	10	2.5%	2.0%	4	1.1%	2.0%
	post-1989	0	0%	0.7%	0	0%	0.7%

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

1. Number of incidents/number of vehicles.
2. The newest incident was for a 1990 model year vehicle.

Table 46 summarizes the average model year for all incidents in the On-Road test program. The average model year for incidents to occur was 1986. On average, the vehicles that had repair incidents were more than 2 years older than the entire fleet-wide average.

Table 46
Average Model Year for All Incidents

Incident Type	Test	Control	All
Fuel pumps	1986	1985	1986
Carburetors	1986	1986	1986
Hose Leaks	1980	--	1980
Seal Leaks	--	1988	1988
Tanks	--	1987	1987
All	**1985**	**1986**	**1986**
Entire fleet	***1987***	***1989***	***1988***

Source: Air Resources Board. 1995 *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

E. Comparing Incident Rates by Weight Class

The incidents were also evaluated by vehicle weight class. Table 47 shows the total incidents and fuel pump incidents by weight for both test and control fleets. Table 47 indicates that the rate of incidents, either observed or expected, increases from light-duty to medium-duty and heavy-duty.

Table 47
All Incidents and Fuel Pumps by Weight Class

Incident Type	Weight class	Test Vehicles			Control Vehicles		
		Incidents Observed	Observed Rate[1]	Expected Rate[1]	Incidents Observed	Observed Rate[1]	Expected Rate[1]
All Incidents	LDV[2]	5	1.3%	3.8%	2	0.6%	3.3%
	M/HDT[3]	19	4.4%	12.4%	18	5.8%	10.4%
Fuel Pumps Replaced	LDV[2]	4	1.0%	1.0%	0	0%	0.8%
	M/HDT[3]	8	1.8%	3.1%	6	1.9%	2.5%

Source: Air Resources Board. 1995 *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

1. Number of incidents / number of vehicles.
2. LDV: Light-duty vehicles.
3. M/HDT: Medium- and heavy-duty trucks and vans.

In both the test and control fleets, the medium- and heavy-duty classes experienced at least 2 times higher observed incident rates when compared with the incidents from light-duty vehicles. This result is not unrealistic, considering that trucks and vans usually operate in a more severe type of service than light-duty vehicles.

F. Comparing Incidents by Fleet

Incidents for the 8 fleets have been summarized in Table 48 by fleet. About 90 percent of all incidents, including test or control, and all of the fuel pump replacements occurred at 2 sites: the General Telephone and Electronics and the Pacific Bell sites in Northern California. Although characteristics such as operation and maintenance of each fleet could be the cause, a specific reason has not been established for why the incidents occurred predominately at these 2 sites.

Table 48
Incidents by Fleet

Fleet	Vehicles	Pumps	Carbs	Hoses	Seals	Tanks	Other
Test							
Bank of America	20	0	0	0	0	0	0
Caltrans	25	0	1	0	0	0	0
City of Sacramento	106	0	0	0	0	0	0
County of Sacramento	173	0	0	0	0	0	0
CSU Fresno	112	0	0	2	0	0	0
GTE	254	7	4	1	0	0	1
Pacific Bell-North	84	5	3	0	0	0	0
Pacific Bell-South	55	0	0	0	0	0	0
Subtotal	829	12	8	3	0	0	1
Control							
Bank of America	10	0	0	0	0	0	0
Caltrans	--	--	--	--	--	--	--
City of Sacramento	81	0	0	0	1	0	0
County of Sacramento	241	0	0	0	0	0	0
CSU Fresno	--	--	--	--	--	--	--
GTE	157	3	2	0	1	2	0
Pacific Bell-North	110	3	5	0	1	2	0
Pacific Bell-South	38	0	0	0	0	0	0
Subtotal	637	6	7	0	3	4	0

Source: Air Resources Board. 1995 *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California

G. Driveability Results

As discussed in Chapter I, the CaRFG test fuel has driveability index values within the acceptable limits regarding vehicle performance. During the test program, fleet owners and drivers were requested to report any driveability concerns with the test fuel on the Driveability/Incident Logs. The driveability/incident logs include the following type of information: cold start, hard start, acceleration, loss of power, and stalling.

In addition, the fleet owners and drivers were questioned regarding how the CaRFG test fuel performed as compared with conventional fuel in terms of driveability, starting, idling, acceleration, loss of power, and safety. The results from the logs during the test program and testimonials indicate that there was no difference in driveability/performance as viewed by the drivers between the test and control fleets.

CHAPTER VII

FUEL ECONOMY

A. Introduction

This Chapter discusses fuel economy. The data from available studies and data from the On-Road test program as well as data from the laboratory dynamometer testing on selected vehicles have been reviewed to determine the effects of gasoline properties on fuel economy. (Appendix 37 summarizes the studies on fuel economy, "Reformulated Gasoline and Volumetric Fuel Economy Discussion," except for the On-Road Test Program and ARB Dynamometer Testing. The Harley-Davidson fuel economy study is discussed in Part Two of this report.)

B. Background on Fuel Economy

Fuel economy is the number of miles per gallon (mpg) of gasoline used. The energy content of gasoline has a direct influence on motor vehicle fuel economy and is expressed in British thermal units per gallon (Btu/gallon). For any specific vehicle, fuel economy varies because it is affected by many parameters such as fuel properties, maintenance practices, engine condition, tire pressure, weather, driving cycle, and the individual driver. Thus, large fluctuations in fuel economy are common.

Table 49
Energy Content of Conventional California Gasoline [1]
1990-1991
(Btu/Gallon)

Time of Year	Mean	Maximum	Minimum	Range (%)
Summer	115,800	120,300	109,900	+3.9% to -5.1%
Winter	114,300	117,700	110,900	+3.0 to -3.0

Source: Air Resources Board. 1991. *Survey of California Gasolines*. Sacramento, California.
1. Includes 597 Gasolines

Table 49 shows that the energy content of conventional gasolines sold in California in 1990 and 1991 varied from 3.9 percent above the mean to 5.1 percent below the mean. Therefore, the energy content of the gasoline from one tank full to another could have varied as much as 9 percent. Gasoline energy content and fuel economy are directly related.

Fuel economy losses are expected to occur due to gasoline reformulation. However, these losses will vary from vehicle-to-vehicle, from fuel-to-fuel, and trip-to-trip. This is due to the differences in engines, fuel systems, gasoline energy contents, and the specific driving conditions. Reformulated gasolines have lower fuel economies because of lower energy densities (energy content per gallon), on average, than conventional gasoline. Generally, reformulating gasoline to reduce emissions results in decreases in the percentage of gasoline that is composed of heavy hydrocarbons, which have higher energy contents than the other gasoline components.

Adding oxygenates, as is done for most reformulated gasolines, can also affect the fuel economy of gasoline because oxygenated compounds have lower energy densities than gasoline. Again, the effects of adding oxygenates to gasoline varies from vehicle-to-vehicle. For example, for a vehicle without oxygen feedback, oxygenates would lean the combustion mixture and could result in a decrease in fuel economy.

Based on an analysis of properties and energy contents of gasoline, it is estimated that gasolines with properties similar to CaRFG would have a 1 to 3 percent lower energy content on average than conventional gasolines. (See Appendix 38 for Volumetric Fuel--Phase 2 Versus Phase 1 Gasoline, February 1995, and Appendix 39 for Statistical Analysis of Fuel Economy Data.)

C. Background Studies on Fuel Economy

1. Auto/Oil Air Quality Improvement Research Program Dynamometer Testing

The fuel economy results of the Auto/Oil Air Quality Improvement Research Program were reviewed. In this study, 34 vehicles from 2 different groups were tested with 29 different test gasolines, including some with properties like CaRFG. The vehicle model years ranged from 1983 to 1989. The analyses indicate that the fleet average fuel economy varied linearly with energy content. (See Appendix 40, "Fuel Composition Effects on Automotive Fuel Economy.")

In more recent dynamometer testing conducted in 1995, the Auto/Oil group tested 32 vehicles. The vehicle model years ranged from 1983 to 1994, with 6 flexible fuel vehicles. From these data, the average fuel economy loss was 2.9 percent when CaRFG was compared with an industry-average test fuel, which is non-oxygenated. (See Appendix 41 for "Letter from
W. M. Kreucher to Dean C. Simeroth and Attachments," April 3, 1995)

2. Battelle On-Road Testing (Federal Express)

Battelle has analyzed fuel economy data from the Federal Express on-road test of 21 delivery vans which operated on a CaRFG test fuel and 9 delivery vans operated on conventional gasoline over a period of two years, September 1992 through August 1994. The vehicles in this study included full-size Chevrolet, Dodge, and Ford vans. The vans were rotated periodically to different driver-routes to minimize driver-route bias in the study. (See Appendix 42 "Vehicle Fuel Economy--the CleanFleet Alternative Fuels Project.")

The test vans in the Battelle study were tested exclusively on CaRFG. The control vans were tested exclusively on conventional gasolines. In comparing the average fuel economy, the differences ranged between 2 percent greater and 11 percent less mpg. Laboratory dynamometer tests were also conducted on the vans for emissions and fuel economy.

3. Wisconsin Department of Natural Resources/U.S. EPA On-Road Testing

In response to fuel economy complaints reported early in 1995, soon after the first phase of federal reformulated gasoline was introduced, the Wisconsin Department of Natural Resources and U.S. EPA embarked on a 2-week test program to evaluate fuel economy issues.

Eight (8) vehicles were tested on 3 different federal reformulated gasolines and 1 conventional non-oxygenated gasoline. The 3 federal reformulated gasolines contained 9.7 percent methyl tertiary butyl ether, 9.3 percent ethanol, or 11.1 percent ethyl tertiary butyl ether. Each vehicle was driven 4 times on each gasoline over a 100-mile route of urban, suburban, and rural roads in Racine and Kenosha County, Wisconsin. The vehicles ranged from 1979 to 1994 in model year and from 7,300 to 143,000 in odometer mileage.

The Wisconsin Department of Natural Resources and the U.S. EPA found a 2.8 percent average drop in fuel economy between conventional gasoline operation and the 3 federal reformulated gasolines. In addition, they found that for any vehicle using the same gasoline, the fuel economy varied at times by more than ten percent between tests. Weather was another factor affecting fuel economy. Between the warm weather in week 1 and the colder weather during week 2 of the test program, fuel economy losses were at least 5 percent for all four fuels, which is greater than the difference in the fuel economy among fuel types. (See Appendix 43 for this study.)

D. The On-Road Test Program Fuel Economy

1. Description

During the On-Road test program, fuel economy data were collected in the form of vehicle odometer readings and fueling quantities for each of the 8 participating test fleets. For the test fleets, fuel samples were taken routinely during the test program and analyzed for properties. Historical data on fuel economy from most of these fleets were also gathered.

2. Methodology

The 1994 historical fuel economy data were compared with the 1995 data from the On-Road test program for both test and control fleets. The data were processed to eliminate fueling records for which the odometer entries were anomalous. The following were calculated: fuel economy over the historical and test periods for each vehicle, the weighted average differences in fuel economy (percent mpg) for each fleet, and the relative difference between the test and control fleets, as applicable.

For the analysis, individual fueling data from the City of Sacramento, County of Sacramento, CSU Fresno, and Bank of America fleets were used. Although monthly fueling data were obtained from General Telephone and Electronic, Pacific Bell (North and South), and Caltrans fleets, the data were too limited in quantity and quality to be used in estimating fuel economy. For the General Telephone and Electronic and Pacific Bell fleets, the quality of the data were limited because the auxiliary equipment on many of these vehicles were powered directly from the main vehicle fuel tank. (See Appendix 39 for Statistical Analysis of Fuel Economy Data.)

3. Fuel Economy Results from the On-Road Test Program

For comparison purposes, the average fuel energy content for both test and control fleets was compared. The energy content was estimated by applying ASTM Test Method D 3338 to the results of the fuel analyses. The results shown in Table 50 indicate that the relative difference in average energy content ranged from -2.5 percent to -4.4 percent, and the relative fuel economy difference was about -2.4 percent.

Table 50
CaRFG Fuel Economy Summary
On-Road Test Fleet Test Program

Participating Fleet	Test Period	Average Energy Content (BTU/gallon)			Fleet Fuel Economy CaRFG vs. Control	
		CaRFG Fleet[1]	Control Fleet	Relative Difference	Relative Difference	Expected Variation
City of Sacramento	Mar-Aug	110400	115500	-4.4%	-2.3%	± 9%[2]
County of Sacramento	Mar-Aug	110700	115600	-4.2%	-2.4%	± 9%[2]
CSU Fresno	May-Aug	110500	None	NA	NA	NA
Bank of America	Mar-July	110300	113700[3]	-3.0%	NA[4]	NA[4]
GTE	Mar-Aug	110400	113600[3]	-2.8%	NA[5]	NA[5]
Pacific Bell, North	Mar-Aug	110400	115400	-4.3%	NA[5]	NA[5]
Pacific Bell, South	Mar-Aug	110300	113100[3]	-2.5%	NA[5]	NA[5]
Caltrans	Mar-Aug	110200	None	NA	NA	NA

Source: Air Resources Board. 1995. *Baseline: Reformulated Gasoline Project*. Sacramento, California.

1. Average of fleet storage tank, time-weighted average, is 110,400.
2. Represents vehicle-to-vehicle variation from historical average; the variation about the fleet-average relative difference is ±3%.
3. Federal Reformulated Gasoline
4. Data are insufficient to analyze appropriately.
5. Auxiliary equipment used fuel from vehicle tank.

E. Laboratory Dynamometer Test Program

A small laboratory dynamometer program was performed to test and evaluate the fuel economy of current vehicle technologies. The goal is to compare CaRFG and federal RFG with conventional gasoline. (See Appendix 44 for ARB Laboratory Dynamometer Test Program.)

1. Test Program Description

Vehicle descriptions. The vehicles tested were the following 1995 model year vehicles: Ford Taurus, Chevrolet Lumina, Honda Accord and Dodge Caravan. Each vehicle represented a major manufacturer, and, if available, the model with the highest projected sales volume for each manufacturer was selected. All of the vehicles had electronic multi-point fuel injection and on-board diagnostic systems. The test vehicles were procured from rental agencies located in Southern California.

Test Fuels. Each vehicle was tested using 3 different summer fuel blends:

1. The On-Road CaRFG test fuel
2. Conventional gasoline, with properties typical of California fuel
3. Federal reformulated gasoline, meeting the federal standards

Table 51
Test Fuel Properties
Dynamometer Fuel Economy Testing

Property	On-Road Test Fuel	Conventional Gasoline	Fed RFG Fuel
RVP, psi	6.9	7.6	6.9
Sulfur, ppm	48	99	45
Aromatic, vol%	18.3	32.8	28.8
Benzene, vol%	0.89	1.66	0.58
Olefins, vol%	5.3	17.9	7.5
Oxygen, wt%	2.04	0.02	2.06
T90, °F	301	332	313
T50, °F	192	210	203
H:C ratio	1.859	1.659	1.743
Specific Gravity	0.7283	0.7523	0.7593
Octane	90	88	89

Source: Resources Board. 1995. *Reformulated Gasoline Project : Fueling Data* Sacramento, California

The On-Road CaRFG test fuel was obtained from the Caltrans test facility during the On-Road test program. Chevron provided the second fuel, a California conventional gasoline, which represents the California fuel currently used in areas that are not required to have federal reformulated gasolines and does not have the fuel additives required for gasoline sold in California. However, due to the small mileage accumulation during the testing, it is unlikely that this affected the fuel economy results. The third fuel represents the federal reformulated gasoline, which was obtained from a service station in the Los Angeles area. Table 51 summarizes the properties of the three fuels used in the fuel economy testing.

Test Program Conduct. Prior to testing, the vehicles were visually inspected and adjusted to manufacturers' specifications. Chassis dynamometer test procedures were conducted according to the Federal Test Procedure (FTP) for city driving fuel economy (40 Code Federal Regulations 86.127-94 through 86.138-94) and the Highway Fuel Economy Test (HWFET) for highway fuel economy (40 Code of Federal Regulations Part 600 Subpart B). The FTP test cycle is run for standard emission tests and represents urban driving conditions. It includes accelerations, decelerations, idling and an average speed of 19 miles per hour. The second test cycle, HWFET, is run for fuel economy tests and was designed to represent highway driving with an overall average speed of 48 miles per hour.

To reset the on-board diagnostics between fuels, the vehicles were preconditioned with 50 miles of on-road driving, encompassing both city and freeway driving. The combined city and highway driving fuel economy estimate was calculated according to 40 CFR 600.113-88. The results are shown in Table 52.

Table 52
Dynamometer Fuel Economy Results
(Combined City and Highway)
in miles per gallon

Vehicle Description	Odometer	Test Fuel CaRFG	Conv.	Fed RFG	Test vs Conv	Test vs Fed RFG
1995 Dodge Caravan	23,139	24.3	24.5	24.8	-0.8%	-2.0%
1995 Ford Taurus	19,363	26.1	27.1	26.8	-3.7%	-2.6%
1995 Chevrolet Lumina	4,846	24.9	26.2	25.6	-5.0%	-2.7%
1995 Honda Accord	20,487	28.8	30.1	28.8	-4.3%	0.0%
Average					**-3.5%**	**-1.8%**

Air Resources Board. 1995. *Reformulated Gasoline Project*. Sacramento, California.

Table 52 provides the fuel economy results of the On-Road test fuel and conventional gasoline. The combined fuel economy has also been calculated for the federal RFG. The differences between the federal RFG and the conventional gasoline, although not shown in the table, were less than the differences between test fuel and conventional gasoline.

F. Fuel Economy Summary

Fuel economy of a given vehicle will vary for many reasons. These reasons include driver influences, fuel variations, driving patterns and weather. Thus, large fluctuations in fuel economy are common. Table 53 summarizes the results of the Subcommittee test programs and the other studies discussed previously. The results of the studies vary for similar reasons that affect individual vehicles. Overall the studies confirm that the average fuel economy using CaRFG will be reduced slightly compared to conventional gasoline; however, the effects for each vehicle and driver will vary.

Table 53
Summary of Fuel Economy Studies
CaRFG versus Conventional Gasoline

Fuel Economy Study	Fuel Economy Difference
Auto/Oil AQIRP Dynamometer Average [1]	-3%
Battelle/Federal Express On-Road [2]	+2% to -11%
Battelle/Federal Express Dynamometer [2]	0% to -6%
Southeastern Wisconsin On-Road Average [3]	-3% (Fed RFG vs. Conventional)
Energy Content Basis (Summer) [4]	-3%
Energy Content Basis (Winter) [4]	-1%
On-Road Fleet Testing [4]	-2%
Dynamometer Testing [5]	-4%

1. April 3, 1995. Letter from W. M. Kreucher to D. C. Simeroth.
2. SAE 950396. Warrendale, Pennsylvania, 1995.
3. Department of Natural Resources and US EPA, March 1995.
4. Air Resources Board/SSD, Sacramento, 1994
5. Air Resources Board/MSD, El Monte, 1995.

Dynamometer Fuel Economy Results
(Combined City and Highway)

Vehicle Description	Odometer	Test Fuel CaRFG	Conv.	Fed RFG	Test vs Conv	Test vs Fed RFG
1995 Dodge Caravan	23,139	24.3	24.5	24.8	-0.8%	-2.0%
1995 Ford Taurus	19,363	26.1	27.1	26.8	-3.7%	-2.6%
1995 Chevrolet Lumina	4,846	24.9	26.2	25.6	-5.0%	-2.7%
1995 Honda Accord LX	20,487	28.8	30.1	28.8	-4.3%	0.0%
Average					**-3.5%**	**-1.8%**

Source: Air Resources Board. 1995. Reformulated Gasoline Project.

Energy Content of Conventional California Gasoline [1], 1990-1991
(Btu/Gallon)

Time of Year	Range (%)	Mean	Maximum	Minimum
Summer	+3.9% to -5.1%	115800	120300	109900
Winter	+3.0 to -3.0	114300	117700	110900

Source: Air Resources Board. 1991. *Survey of California Gasolines* . Sacramento, California.
1. Includes 597 Gasolines

PART TWO

CHAPTER I

INTRODUCTION

A. Summary

Part Two of this report presents the various industry-sponsored test programs to determine the compatibility and performance of California reformulated gasoline, referred to as CaRFG, with fuel system components.

Six companies tested various blends of CaRFG to test the compatibility and performance of CaRFG with fuel system components. Some test programs were exclusively bench tests or in-use tests while other test programs combined both.

B. Role of the Performance Subcommittee

The companies who conducted these test programs were all members of the Performance Subcommittee (Subcommittee). However, the Subcommittee did not formally approve the test programs although the individual companies discussed their programs with the Subcommittee.

C. Structure of Part Two

Chapter II presents the employee fleet test program conducted by Chevron Research and Technology Company

Chapter III presents the gasoline dispensing equipment evaluation by EMCO Wheaton Incorporated and Dayco Products Incorporated.

Chapter IV presents the Lubricity Testing program conducted by Ford Motor Company.

Chapter V presents the Fuel System Elastomers and Plastics Bench Tests conducted by General Motors Corporation

Chapter VI presents the comprehensive test programs conducted by Harley-Davidson.

Chapter VII presents the carburetor and other components analysis performed by Holley Performance Products.

Chapter VIII presents the in-use and bench tests conducted by Nissan Motor Company.

Chapter IX presents the low aromatics in-use test programs conducted by Texaco Marketing & Refining.

Chapter X presents On-road Mileage Accumulation Testing Program results by the U. S. Department of Energy.

CHAPTER II

CHEVRON ON-ROAD TEST PROGRAM

A. Introduction

The Chevron U.S.A. Products Company conducted its own On-Road test program to supplement the ARB On-Road test program. The Chevron program was designed to provide information on a fleet with older and imported vehicles. (See Appendix 1 for details on the Chevron Test Program.)

B. Chevron Fleet Test Program

The Chevron fleet was an employee fleet of privately owned and operated vehicles which was chosen to include imported vehicles and emphasize a fleet with older vehicles than the ARB On-Road test fleet of 829 test vehicles and 637 control vehicles. The Chevron test fleet comprised 118 vehicles operated on the Chevron test fuel and a control fleet of 117 vehicles operated on conventional, California wintertime oxygenated gasoline. The Chevron test fuel met the CaRFG standards but did not have the same properties as the On-Road test fuel. For example, the Chevron test fuel had lower aromatic hydrocarbon, sulfur, and benzene content. The properties of the Chevron test fuel and conventional control fuel are listed in Table 1.

Table 1
Chevron Test Fuel Parameters

Fuel Parameter	On-Road Test Fuel (Summer)[1]	Chevron Test Fuel[2]	Conventional/ Control Fuel[2]
Aromatics, vol%	18.4	13.7	25.1
Benzene, vol%	0.89	0.24	2.2
RVP, psi	6.6	8.3	13.0
T50, °F	190	183	182
T90, °F	298	288	306
Sulfur, ppmw	52	15.5	107
Oxygen, wt%	2.09	2.1	1.9
Olefins, vol%	5.7	5.0	14

Source:
1. Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.
2. Chevron Corporation. July 18, 1995. "Presentation to Performance Subcommittee." Sacramento, California.

Chevron employees volunteered for the test program. They agreed to use the test fuel as often as practically possible; however, Chevron employees were unaware whether or not they were using test or conventional fuel. At the beginning of the program, in January 1995, Chevron mechanics inspected the vehicles for fuel-system and other problems. The vehicles were again inspected in April 1995 and at the end of the test program in June 1995. Table 2 summarizes the vehicles in the Chevron on-road test program by age, odometer readings, and weight class and compares the Chevron fleet with the California average fleet of light-duty vehicles. As can be seen in Table 2, the Chevron fleet is older than the overall California average fleet and has about twice the percentage of pre-1981 vehicles. Table 3 compares the Chevron fleet with the On-Road program fleet.

Table 2
Distribution by Model Year and Mileage
Chevron Fleet

Weight Class	Mileage (x1000)	Test Fleet					Control Fleet				
		<1981	1981-84	1985-89	>1989	Total	<1981	1981-84	1985-89	>1989	Total
Light Duty Auto	<50	1	0	2	19	22	0	1	3	15	19
	50-100	7	1	22	4	34	3	6	24	7	40
	>100-150	10	10	15	1	36	13	9	16	0	38
	>150	11	11	4	0	26	10	4	6	0	20
Total		29	22	43	24	118	26	20	49	22	117
Chevron Fleet[1]		24.6%	18.6%	36.4%	20.3%	100%	22.2%	17.1%	41.9%	18.8%	100%
California Fleet[2]		12.7%	11.6%	29.6%	46.1%	100%	12.7%	11.6%	29.6%	46.1%	100%

Source:
1. Chevron Corporation. October 26, 1995. "Chevron FAX to Air Resources Board". Sacramento, California.
2. Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

Note: The vehicle counts identified above are final per Chevron's determination of what vehicles are valid for their test and control fleets. Some vehicles were voluntarily removed too early to be considered valid.

The participants logged their fuel usage and any driveability incidents. Incidents that were potentially fuel related were either repaired free of charge by Chevron mechanics or the cost of repairs were reimbursed to the employee if repairs were made by another repair facility. Chevron engineers analyzed all failed parts; Chevron shared its results with the technical review panel who reviewed the information.

Table 3
On-Road Program Fleet and Chevron Fleet Distribution by Mileage and Model Year

Test Program	Mileage (x1000)	Test Fleet					Control Fleet				
		<1981	1981-84	1985-89	>1989	Total	<1981	1981-84	1985-89	>1989	Total
ARB On-Road Program Fleet	<50	20	13	111	188	332	3	13	115	153	284
	50-100	26	43	248	88	405	1	13	216	84	314
	>100-150	13	25	38	1	77	0	14	17	6	37
	>150	7	3	5	0	15	0	1	1	0	2
	Total	66	84	402	277	829	4	41	349	243	637
Chevron Program Fleet	<50	1	0	2	19	22	0	1	3	15	19
	50-100	7	1	22	4	34	3	6	24	7	40
	>100-150	10	10	15	1	36	13	9	16	0	38
	>150	11	11	4	0	26	10	4	6	0	20
	Total	29	22	43	24	118	26	20	49	22	117
Chevron Fleet[1]		24.6%	18.6%	36.4%	20.3%	100 %	22.2%	17.1%	41.9%	18.8%	100 %
California Fleet[2]		12.7%	11.6%	29.6%	46.1%	100 %	12.7%	11.6%	29.6%	46.1%	100 %

Source:

1. Chevron Corporation. October 26, 1995. “Chevron FAX to Air Resources Board”. Sacramento, California.
2. Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.

C. Results of the Chevron On-Road Test Program

Table 4 summarizes the vehicle incidents during the Chevron test program as reported by Chevron.

Table 4
Summary of Total Chevron Vehicle Incidents

Type of Incident	Test Group (Chevron Test Fuel)	Control Group (Conventional Fuel)	Are incidents fuel related?[1]
Intermittent/One time	6	7	no
Electrical/Mechanical	13	10	no
Fuel filters / Regulators/ Dirt in Carburetor	6	4	no
Elastomers / Seals	6	1	maybe
Total	31	22	---

Source: Chevron Corporation. 7/18/95. "Presentation to Performance Subcommittee." Sacramento, California.
1. Judgement by Chevron engineers.

Chevron engineers carefully evaluated each incident and determined that only the elastomer incidents can be classified as “maybe” fuel related, which were consistent with the criteria used by the technical review panel. Although, the program was not designed to analyze incident rates by type of component, Table 5 shows the frequency of elastomer incidents by fuel system component type as categorized by ARB staff.

For the elastomers and seals, there were 6 incidents in the test fleet and 1 in the control fleet. Chevron considered this overall difference in incident rates between the test and control fleets to be statistically significant. However, the ARB’s analysis, when Chevron’s data were combined with the ARB’s On-Road test results, did not show a statistically significant difference (See section D and Appendix 15). Further, Chevron’s conclusion is sensitive to small changes in the numbers of incidents. For example, if a single additional incident had occurred in the control fleet, the results would not have been considered statistically significant by Chevron. Although the Chevron program was designed to compare only the difference in overall incident rates between the test and control fleets, when the differences between the proportion of incidents are compared by component incident type, the differences are not considered statistically significant.

Table 5
Frequency of Possibly Fuel-Related Incidents by Component Type In Chevron Test Program

Component Type	Incidents			
	Test Fleet		Control Fleet	
	number	percent	number	percent
Fuel Pumps	3	2.5%	1	0.9%
Carburetor	1	0.8%	0	0%
Hose	2	1.7%	0	0%
Seal	0	0%	0	0%
Fuel Tank	0	0%	0	0%
Fuel Injector	0	0%	0	0%
Other	0	0%	0	0%
Total	**6**	**5.1%**	**1**	**0.9%**

Source: Chevron Corporation. July 18, 1995. "Presentation to Performance Subcommittee." Sacramento, California.

D. Results of the On-Road and Chevron Test Programs Combined

The combined data from the Chevron test program and the On-Road test program were analyzed. The combined Chevron and On-Road test program data provide more complete coverage of the California on-road vehicle population than either program achieved separately.

Table 6 lists all of the repairs that "may be" fuel-related for both the On-Road and Chevron test programs.

Table 6
Summary of Vehicle Incidents that May be Fuel Related
On-Road and Chevron Fleet Combined

Component Type	Test Fleets (Chevron Test Fuel)	Control Fleets (Conventional Fuel)
Fuel Pumps	15	7
Fuel Lines	5	0
Carburetors	9	9
Fuel Injectors	0	0
Fuel Tanks	0	5
“Other”	1	0
Total	30	21

Source: Chevron Corporation. July 18, 1995. "Presentation to Performance Subcommittee." Sacramento, California.
Air Resources Board. 1995. *Baseline Data: California Reformulated Gasoline Project* . Sacramento, California.

Table 7
Observed, Expected and Normalized Incident Rates
On-Road and Chevron Fleets Combined

Component Type	**Test Fleet**				**Control Fleet**			
	Vehicles	Observed	Expected	Normalized	Vehicles	Observed	Expected	Normalized
Fuel Pumps	947	1.6%	2.0%	1.6%	754	0.9%	1.6%	1.3%
Fuel Lines	947	0.5%	1.8%	0.5%	754	0.0%	1.5%	0.3%
Carburetors	947	1.0%	2.1%	1.0%	252	1.2%	1.5%	1.8%
Fuel Injectors	947	0.0%	0.7%	0.1%	754	0.0%	0.8%	0%
Fuel Tanks	947	0.0%	1.3%	0%	754	0.7%	1.1%	0.9%
Total	**947**	**3.2%**	**7.9%**	**3.2%**	**754**	**2.8%**	**6.5%**	**4.2%**

Source: Chevron Corporation. July 18 1995. "Presentation to Performance Subcommittee." Sacramento, California.
Air Resources Board. 1995. *Baseline Data: California Reformulated Gasoline Project* . Sacramento, California.

Table 7 shows the observed, expected, and normalized incident rates after correcting for the differences in the baseline rates. Because the fleets are not perfectly balanced with respect to vehicle characteristics, the normalized rates in Table 7 were developed to be directly comparable and provide a meaningful basis for determining the differences between the test and control fleets. For the combined On-Road and Chevron fleets, the differences between the normalized rates are not considered statistically significant and should not be attributed to differences between the fuels used.

Table 8 shows the average odometer readings and ranges for all incidents in both test and control fleets in the On-Road and Chevron test programs. On average, for the test fleet, the incidents occurred at odometer readings of about 105,000 miles, with a range of 24,000 to 202,000 miles. For the control fleet, the incidents occurred at odometer readings of about 91,000 miles, with a range of 24,000 to 184,000. The overall average mileage for incidents for the test and control fleets combined is about 99,000 miles, with a range of 24,000 to 202,000. Table 8 also shows that, on average, the incidents occurred at about 15,000 miles higher on test vehicles than control vehicles.

Table 8 also shows the average odometer readings for the fleet for both the test and control vehicles. For both the test and control fleets, the incidents occurred in vehicles with 30,000 to 40,000 miles higher than the average miles for the total vehicles in the On-Road and Chevron fleets. Thus, as in the baseline data (Part One), mileage seems to be an important factor in the occurrence of fuel system problems.

Table 8
Average Odometer Readings and Range for Incidents
On-Road and Chevron Fleets Combined

Component Type	Test	Range	Control	Range	Combined Test and Control	Range
Fuel Pump	112,000	24,000-202,000	116,000	36,000-184,000	113,000	24,000-202,000
Carburetor	89,000	39,000-160,000	76,000	24,000-132,000	83,000	24,000-160,000
Hose Leak	107,000	40,000-202,000	--	--	107,000	40,000-202,000
Seal Leak	--	--	77,000	68,000-92,000	77,000	68,000-92,000
Fuel Tank	--	--	82,000	34,000-139,000	82,000	34,000-139,000
Other	130,000	--	--	--	130,000	--
Average	105,000	24,000-202,000	91,000	24,000-184,000	99,000	24,000-202,000
On-Road and Chevron Fleet[1]	**67,000**	**13-234,000**	**64,700**	**80-179,000**	**66,000**	**13-234,000**

Source: Air Resources Board. 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.
Chevron Corporation. October 17, 1995. "Presentation to Performance Subcommittee." Sacramento, California
1. Data for total vehicles in the On-Road and Chevron fleets.

Table 9 summarizes the average model year for all incidents in the On-Road test program. The average model year for incidents to occur was 1985. On average, the vehicles that had repair incidents were more than 2 years older than the average for the entire test and control fleets combined. Table 10 summarizes the data from Tables 8 and 9.

Table 9
Average Model Year for Incidents
On-Road and Chevron Fleets Combined

Component Type	Test	Control	Combined Test and Control
Fuel pumps	1985	1985	1985
Carburetors	1984	1986	1985
Hose Leaks	1978	--	1978
Seal Leaks	--	1988	1988
Tanks	--	1987	1987
Other	1983	--	1983
Average	**1984**	**1986**	**1985**
Entire On-Road and Chevron Fleet	***1987***	***1988***	***1987***

Source: Air Resources Board. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.
Chevron Corporation. July 18, 1995. "Presentation to Performance Subcommittee." Sacramento, California

Table 10
Average Model Year and Odometer Readings for Incidents
On-Road and Chevron Fleets Combined
(Test and Control)

Fleet	Average Model Year	Average Odometer Reading (Miles)	Range of Odometer Readings (Miles)
On-Road	1986	95,000	24,000-202,000
Chevron	1985	106,000	37,000-182,000
Combined On-Road and Chevron	1985	99,000	24,000-202,000

Source: Air Resources Board. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project.* Sacramento, California.
Chevron Corporation. July 18, 1995. "Presentation to Performance Subcommittee." Sacramento, California

E. Discussion of Results

In the On-Road test program, 3 percent of the test vehicles and 3 percent of the control vehicles showed problems in fuel systems (fewer than expected from historical data). In the Chevron Test Program, 5 percent of the test vehicles and 1 percent of the control vehicles showed problems in fuel systems. (None of these incidents were positively identified as being caused by fuel; the incident rate was lower than expected based on the On-Road test program historical data).

The ARB On Road test program produced no meaningful indications of harm to vehicles by the test fuel. The Chevron program showed more problems in their test fleet than the control fleet although the ARB's analysis of the combined data indicates that the difference is not significant.

The Chevron employee fleet study was designed to complement the larger On-Road test program, with more emphasis on older, higher mileage vehicles. Incorporating the Chevron data into the On-Road test program data does not change the findings described in Part One. Within the Chevron test program, there were more incidents in the 118 vehicle test fleet than in the similar number of vehicles in the control fleet. However, the Chevron incident frequency rate is lower than the baseline failure rate that would be expected in an aged, high mileage fleet. Furthermore, the typical pattern of failures observed is very consistent with the expected failure of mechanical fuel pumps and other elastomer parts on older, high mileage vehicles based on available data. When evaluated in conjunction with the larger ARB On-Road test program, the difference in failure rates between the Chevron test and control fleets were not considered to be substantial enough to conclude that there could be increased failure rates among vehicles in general from the use of CaRFG. The Chevron results are consistent with the results of the other test programs and review of repair records for vehicles operating on cleaner-burning gasoline and conventional gasolines, all of which indicate that older, higher mileage vehicles may have a higher risk of fuel system problems.

CHAPTER III

EMCO WHEATON AND DAYCO PRODUCTS TEST PROGRAMS

A. Introduction

This Chapter discusses the laboratory tests and in-use tests performed by EMCO Wheaton, Incorporated, (EMCO Wheaton) and Dayco Products Incorporated (Dayco) to evaluate CaRFG compatibility with gasoline dispensing hoses and nozzles. (See Appendices 2 and 3 for more details on EMCO Wheaton Incorporated and Dayco Products Incorporated test programs, respectively.)

B. Background on EMCO Wheaton and Dayco Test Programs

With the assistance of the ARB, EMCO Wheaton and Dayco developed test protocols. The objective of the test program is to evaluate the effects of the test fuel on gasoline dispensing equipment, which contains polymer materials and metallic components.

EMCO Wheaton provided 4 nozzles and Dayco provided 3 hoses to be used on gasoline dispensing equipment during the On-Road vehicle test program. The dispensing equipment was attached to gasoline pump dispensers at 2 test fleet sites in Sacramento, California: 2 pumps at the Sacramento City Police Department and 1 pump at the Sacramento Pacific Bell facility. The equipment used included 3 new EMCO Wheaton vapor recovery coaxial nozzles, model A4005-002, and 3 new 12 foot Dayco coaxial hoses, model 7574.

To ensure continuity in equipment, 3 new backup nozzles of the same model were provided in the event that the original equipment was damaged. However, because the nozzles were equipped with breakaways, it was not deemed necessary to provide hose backups. At the end of the On-Road program, the equipment was returned to the respective company for analysis.

C. EMCO Wheaton Test Program

1. Testing

EMCO Wheaton conducted various laboratory tests on 4 nozzles to evaluate the mechanical wear and deterioration caused by the use with or exposure to the On-Road test fuel.

The evaluation was based on the following comparisons:

- Deterioration of equipment used in the On-Road test program compared with new, unused equipment
- Deterioration of new, unused equipment subjected to static immersion in the On-Road test fuel compared to equipment used in the On-Road test program.
- Mechanical operating effectiveness of new equipment subjected to static immersion, compared with new, unused equipment.
- Mechanical operating effectiveness of the equipment used in the On-Road test program compared with new, unused equipment.

These tests were performed following the specifications of Underwriters Laboratory method 842, Standard for Valves for Flammable Fluids, Seventh Edition, June 3, 1993, except for immersion tests. The immersion tests were performed over a 70 hour period, according to the Underwriters Laboratory method 330, Standard for Gasoline Hose, August 21, 1978 specifications. The tests were applied to all non-metallic parts, using samples of summer and winter On-Road test fuels. EMCO Wheaton evaluated the degree of swelling, shrinkage, and deterioration of the properties of the material.

In addition to these tests, at the end of the On-Road test program, EMCO Wheaton personnel, at their engineering laboratory in Morrisville, North Carolina, evaluated the nozzles used in the On-Road test program for mechanical wear and deterioration. The equipment was completely disassembled; the main body was cut in half, longitudinally, and the aluminum casing examined for corrosion.

2. Results of EMCO Wheaton Test Program

Based on its test results, EMCO Wheaton staff indicate that CaRFG is acceptable to use with their A4000 nozzles. However, they did not test some of the compounds now used in the A4500/05 nozzles. Therefore, the overall effect of the CaRFG on the A4500/05 cannot be determined at this time.

EMCO Wheaton considers the test results, for winter and summer CaRFG fuel samples, to be very satisfactory for the following reasons:

- The values obtained are significantly below the maximum acceptable limit.
- The CaRFG has significantly less effect on nozzle component properties than the standard test fuel that EMCO Wheaton used. (See Table 11 for the data.)

The table shows the mean loss of weight and the mean volume swell for 4 tests on each of 12 components of nozzles. EMCO Wheaton tested both the summer and winter CaRFG test fuels, and its own standard test fuel, which is 20% volume ethanol in premium grade.

Regarding the results on the nozzles used in the On-Road program, EMCO Wheaton indicated that CaRFG did not adversely affect equipment. There were no signs of deformation on O-rings, seals, or diaphragms. In addition, the metal and plastic parts were in good condition.

Table 11
Results of EMCO Wheaton Immersion Testing
(Standard Test Fuel[1] Versus CaRFG)

Component	**Standard Test Fuel**		**Winter CaRFG Test Fuel**		**Summer CaRFG Test Fuel**	
	Volume Swell (%)	Weight Loss (%)	Volume Swell (%)	Weight Loss (%)	Volume Swell (%)	Weight Loss (%)
Diaphragm	--	--	34	0	26	2
O-ring (press. cap)	23	7	8	6	9	7
O-ring (spout)	28	8	8	6	4	10
O-ring (dia-cap)	26	7	6	7	4	10
O-ring (vapor guide)	7	0	4	0	3	1
O-ring (fuel inlet)	23	10	9	4	7	9
Disc Seal	5	0	3	0	2	0
O-ring (main cage)	24	7	16	0	8	5
Vapor Seal	32	5	13	3	12	4
Boot Face	37	0	4	0	4	0
Vapor Bellows	25	0	7	0	14	0
P/D Assembly	28	9	8	8	7	8
Average	24	5	10	3	8	5

Source: EMCO Wheaton. 8/23/95. "Inter-Office Correspondence Regarding CARB Fuel Testing." Wilson, North Carolina.

1. 80% premium and 20% ethanol. Maximum allowable swell is 40%; maximum allowable weight loss is 10%.

D. Dayco Test Program

1. Testing

Dayco conducted various laboratory tests on 3 hoses according to specifications of the Underwriters Laboratory 330, Standard for Gasoline Hose, August 21, 1978. The following tests were performed:

- Tensile Strength
- Elongation
- Modulus of Elasticity
- Percent change in Tensile Strength
- Percent change in Elongation

Also, the durometer test was performed according to ASTM Method D-2240-91, Standard Test Method for Rubber Property, Durometer Hardness. In addition, Dayco performed immersion tests on new materials with samples of the On-Road summer and winter test fuels. The tests included volume swell and ozone testing.

2. Results from the Dayco Test Program

Dayco has asked that the actual results of their analyses be kept confidential. However, they indicated that the immersion test results with samples of the winter and summer fuel were satisfactory, and in some cases better than with some conventional gasolines presently in use. Tests on the returned field hoses also produced results which were within acceptable ranges.

E. Survey of Other Companies

To obtain additional background information, a survey was conducted with other companies who manufacture hoses and nozzles for gasoline pumps (or companies who are involved with the manufacture of gasoline dispensing equipment). The companies were questioned about how a range of low aromatic hydrocarbon fuels might effect their products. All company staff indicated that their equipment could be used with CaRFG. (See Appendix 4 for survey results.)

CHAPTER IV

FORD MOTOR COMPANY
GASOLINE LUBRICITY TEST PROGRAM

A. Introduction

The Ford lubricity test program compared various CaRFG test gasolines with previously tested fuels to assess whether CaRFG might present any special concerns related to lubricity. The test program, fuels, and results are discussed in the following section. (See Appendix 5 for more details on Ford test program.)

B. Ford Motor Company Lubricity Bench Test Program

The purpose of this study was to provide an assessment of the lubricity characteristics of CaRFG and variations of this gasoline which may be sold commercially throughout the state beginning in 1996. Ford tested 4fuels using a bench test procedure to provide a relative comparison of lubricity characteristics. Table 12 shows the properties of the 4 fuels tested by Ford for this program.

Table 12
Properties of Lubricity Test Fuels

	CaRFG	CaRFG w/ Low Aromatics	CaRFG w/ Ethanol	Industry Ave. (A/O Fuel A)
Aromatics (vol%)	21.3	15.0	19.1	32.0
Olefins (vol%)	5.0	5.0	4.2	9.2
Sulfur (ppm)	43.2	19.6	16.0	339
Benzene (vol%)	0.8	0.7	0.9	1.53
Oxygen (wt%)	2.0 MTBE	2.0 MTBE	2.0 Ethanol	0
T50 (ºF)	190	191	194	218
T90 (ºF)	297	299	295	330
RVP (psi)	7.0	6.7	8.3	8.7
Octane (R+M)/2	90	91	90	87.3

To determine whether CaRFG may potentially cause an increase in engine or fuel component wear, the test fuels were compared with fuels used in the Auto/Oil Air Quality Improvement Research Program. The Auto/Oil fuels were previously tested for lubricity using the same procedure as in this study. The Auto/Oil blends represented a cross-section of gasolines which may be found in commercial use and included Industry Average Fuel A, a non-oxygenated, non-reformulated conventional gasoline.

The lubricity characteristics of the test fuels were evaluated using a bench-top wear test machine developed by Fluid Technologies, Inc. The apparatus provides a relative lubricity rating for each fuel by measuring the wear rate of brass bearings forced against a rotating journal immersed in the test fluid. The test fluid is circulated though a filter and a heat exchanger to reduce particle contamination and to maintain a controlled fluid temperature. The bearings are held against the journal at a constant load using a gear-driven mechanism. The wear rate is recorded as the number of gear teeth advanced over a 30 minute test period. This wear rate (the linear wear rate of the bearing on the journal) is defined as the Lubricity Index which provides a relative comparison of fuel wear rates. The correlation between the Lubricity Index and component wear rate has been demonstrated in a previous study. Industry Average Fuel A was tested in the original Auto/Oil test set and again in this experiment to provide a measure of the consistency of the test procedure.

C. Results of the Ford Gasoline Lubricity Bench Test Program

The relative lubricity characteristics of the 4 test fuels, indicated by the Lubricity Index, are presented below. A higher Lubricity Index generally signifies higher wear characteristics.

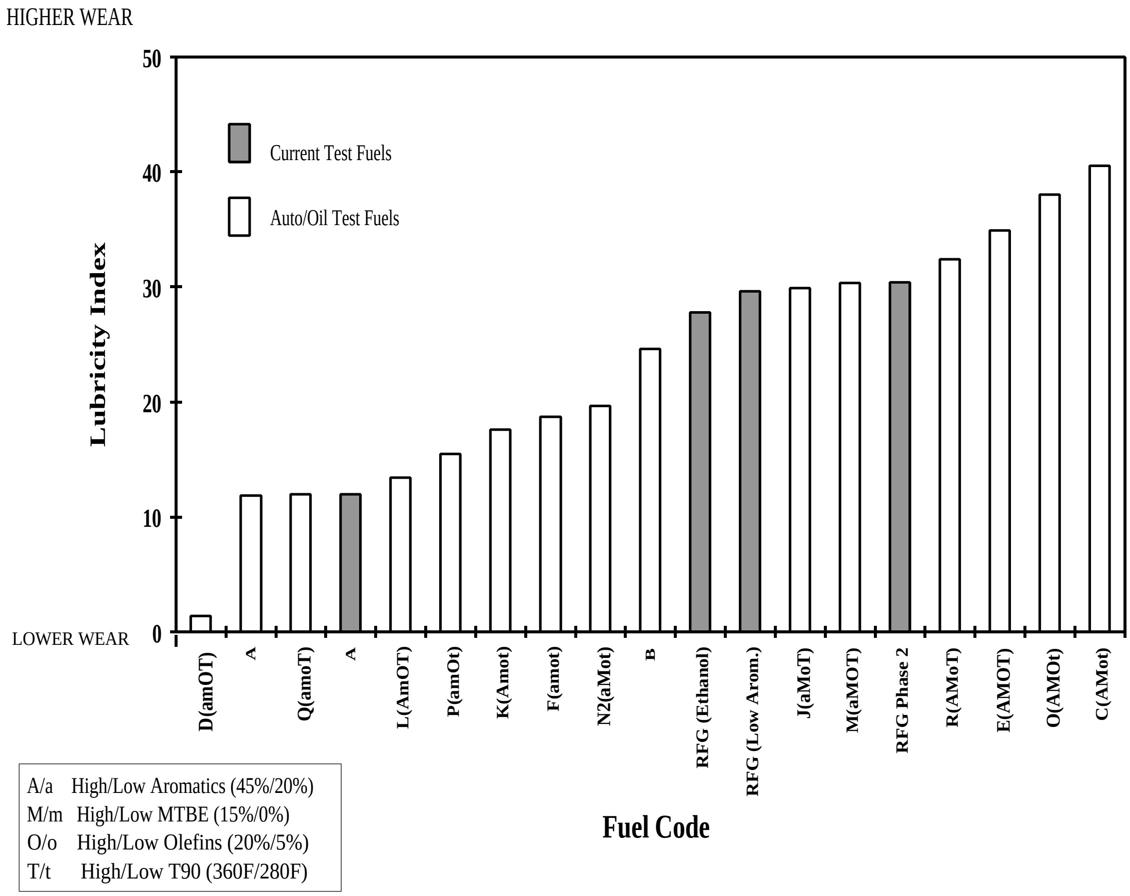
Lubricity Index	Test Fuel
30	CaRFG
30	CaRFG w/ Low Aromatics
28	CaRFG w/ Ethanol
12	Industry Average A (Fuel A)

The Lubricity Indices for the 4 test fuels are also shown along with the previously tested Auto/Oil fuels in Figure 1 to illustrate how these test fuels compare with other fuels which may be found in commercial use. The results of the lubricity testing indicate that the reformulated gasolines examined here have somewhat higher wear characteristics than the Industry Average Fuel A. The results also indicate that the lubricities of the test fuels are well within the range of the broad spectrum of Auto/Oil test fuels.

The previously tested Auto/Oil fuels presented in Figure 1 were blended at two levels each of 4 parameters - aromatics, olefins, oxygenate (MTBE was used) and T90. The lubricity test results of these fuels suggest that generally, higher aromatics and the presence of an oxygenate contribute the most in reducing lubricity. The formulation of the 4 CaRFG test fuels and their relative ranking in Figure 1 are consistent with this trend.

These data suggest that the lubricity characteristics of CaRFG and variations of it are not unusual or markedly different from other commercially available gasolines.

Figure 1
Current Test Fuels Compared with Auto/Oil Test Fuels



CHAPTER V

GENERAL MOTORS BENCH TEST PROGRAM

A. Introduction

General Motors volunteered to conduct bench tests of typical fuel system elastomers and plastics to evaluate the compatibility of CaRFG with these materials under laboratory conditions. This chapter discusses the GM bench test program and its results. (Appendix 6 presents more detailed results from the GM study.)

B. General Motors Bench Test Program

Bench tests were performed at General Motors Delphi Energy and Engine Management Systems (Delphi-E) laboratories to measure the effects of CaRFG and conventional gasoline blends on unused fuel system elastomers and plastic materials. A test matrix consisting of 5 test fuels and 10 material samples, 5 elastomers and 5 plastics, was originally planned.

Three of the fuels were blended by Phillips to comply with the CaRFG requirements. These fuels were the ARB On-Road test fuel, designated in this chapter as CaRFG-T; a fuel similar to the On-Road test fuel, but blended with ethanol as the oxygenate, rather than MTBE, designated CaRFG-E; and a blend selected with low aromatic content, designated CaRFG-LA. The other two fuels were non-oxygenated hydrocarbon blends. One of these, designated RFA, was from the Auto/Oil Air Quality Improvement Research Program test fuel matrix and represents a national average non-oxygenated gasoline. The other fuel, designated ASTM-C, was American Society of Testing Materials Reference Fuel C, a blend of iso-octane and toluene. These latter two fuels were selected to provide a conventional fuel baseline for comparison, and to provide a comparison with previous testing done at the Delphi-E laboratories. (The results of the CaRFG and RFA test fuel analyzes are in Appendix 6, Tables 3a through 7b.)

Some delay was experienced in obtaining the test fuels. In order to facilitate completion of the GM bench tests in the same time frame as completion of the vehicle tests, only 9 fuel system materials were evaluated. Because of the similarity in expected performance of the material omitted (a high fluorine content fluorocarbon elastomer compound, VITON GFLT) to the VITON A material evaluated, this deletion does not impact the overall bench test program conclusions. VITON GFLT has been used in alcohol fuel flexible vehicle designs, but its cost has made it an unlikely choice for gasoline vehicle fuel systems. The elastomers and plastics evaluated in the GM bench tests are listed below.

Elastomers	Plastics
VITON A (fluorocarbon)	Polybutyl terephthalate (PBT)
Buna-N rubber	Polyphenylene sulfide (PPS)
Epichlorohydrin	Saran/polyester (woven fuel filter)
Fluorosilicone	Foamed urethane (float material)
	Nitrophyl (foamed nitrile float material)

The fuel system elastomers and plastics were subjected to two types of tests. Both of these test procedures represent more severe environments than usually encountered in normal vehicle operation. The test procedures are designed to accelerate fuel system material property changes to facilitate material selection. The test results are most valuable when used in a comparative manner. For this reason, the inclusion of the conventional, hydrocarbon gasoline blend RFA and the ASTM Reference Fuel C was critical to a valid evaluation of the impacts of various CaRFG blends.

Two bench test procedures were used. In the first, the fuel system material samples were refluxed in the test fuel at the initial boiling point of the fuel. The reflux test apparatus operated at atmospheric pressure. For the test fuels used in this series of tests, the initial boiling temperature was in the range of 37-41 °C for the CaRFG blends and RFA, but was 98 °C for ASTM-C. All 4 of the elastomers and the Saran/polyester fuel filter material were reflux tested to 1000 hours; the foamed urethane and the Nitrophyl samples were reflux tested for 24 hours. The reflux test results presented in this chapter represent averages of a minimum of 5 samples of the test material at each test duration; twenty samples of the foamed materials were evaluated.

In the second bench test procedure, samples of the fuel system materials were immersed in the test fuel, in a sealed vessel known as a Parr bomb. The Parr bomb was placed in an oven, and the sample and fuel were heated to 100 °C. Because the test material sample and the fuel were heated in a sealed vessel, the test pressures were increased above atmospheric pressure, ranging from about 245 kPa to 360 kPa. Multiple bomb assemblies were used, allowing samples to be removed for property evaluations at various test times, up to a maximum test time of 1000 hours. The Parr bomb results presented in this chapter represent an average of a minimum of 5 samples of the test material, at each test duration. For the CaRFG and RFA fuel tests, the test fuel was replaced by CaRFG-LA at 500 hours to simulate the effects of exposure to a low aromatic fuel on a used component. All 4 of the elastomer types and samples of PBT and PPS plastics were evaluated in the Parr bomb tests.

C. Results of General Motors Bench Tests

Fuel System Plastics. Testing of all of the plastic materials originally included in the bench test matrix have been completed. The results of the reflux tests of the Saran/woven polyester fuel filter material and of the foamed float materials are shown in Table 14. Parr bomb test results for the PBT and PPS material samples are shown in Tables 15 and 16.

The Saran fuel sock exhibited a small volume change along with some hardening in the reflux tests. The material color changed from pale green to very dark brown in all of the test fuels. None of these changes are expected to impact the material performance as an in-tank fuel filter. Volume and density changes in the foamed urethane and Nitrophyl float materials were not sufficient to affect the performance of these materials as carburetor or fuel level sending unit float materials. Visual appearance at the end of the test was acceptable in all of the test fuels, indicating no impact on the physical integrity of the float materials. (The complete fuel filter and material test results can be found in Appendix 6, tables 8a, 8b, and 8c.)

Table 14
Summary of Weight Percent Change of Reflux Tests
Fuel System Plastic Materials

Material	CaRFG-T	CaRFG-E	CaRFG-LA	RFA	ASTM-C
Saran/Polyester Fuel Filter (1000 hours reflux)[1]	-2.2%	-2.2%	-2.2%	-2.2%	-2.2%
Foamed Urethane Floats (24 hours reflux)	-1.0%	-0.3%	-1.6%	-1.8%	-1.7%
Nitrophyl Floats (Foamed Nitrile) (24 hours reflux)	-0.28%	-0.03%	-0.28%	-0.24%	-0.05%

Source: General Motors Corporation. February 1996. *Bench Test for the Performance Subcommittee*. Detroit, Michigan.

1. At 500 hours test time, CaRFG and RFA samples switched to CaRFG-LA.

In the Parr bomb tests, exposure of "used" PPS samples to low aromatic content fuels, simulated by switching from the initial test fuel to CaRFG-LA test fuel at 500 hours, showed a reversal in the trend of some of the property changes. However, the observed PPS property changes were considered normal for these tests. This was also true for the PBT samples, except that PBT did not perform well in the ethanol blend test fuel, CaRFG-E. Excepting this material-test fuel combination, the property changes observed for the CaRFG blends were comparable to those observed in RFA. (Complete test results from the Parr bomb tests of fuel system plastics are given in Appendix 6, tables 9a, 9b, and 9c.)

Table 15
Summary of Parr Bomb Tests
Fuel System Plastic Materials
500 Hour Results

Percent Change in Material Property	**CaRFG-T**	**CaRFG-E**	**CaRFG-LA**	**RFA**	**ASTM-C**
Polybutylene Terephthalate (PBT)					
Tensile Strength	-21%	-76%	-17%	-25%	-33%
Ultimate Elongation	2%	-77%	12%	9%	8%
Tensile Modulus	-17%	-24%	-18%	-22%	-34%
Izod Impact Strength[1]	---	---	---	---	---
Volume	2.5%	4.3%	2.3%	3.7%	5.0%
Weight	1.7%	2.6%	1.4%	2.2%	3.0%
Polyphenylene Sulfide (PPS)					
Tensile Strength	6%	2%	3%	9%	16%
Ultimate Elongation	-5%	12%	9%	16%	37%
Tensile Modulus	-5%	-6%	-2%	-2%	-4%
Izod Impact Strength[1]	---	---	---	---	---
Volume	0.4%	1.4%	0.3%	1.6%	3.2%
Weight	0.4%	1.1%	0.2%	0.8%	2.1%

Source: General Motors Corporation. February 1996. *Bench Test for the Performance Subcommittee*. Detroit, Michigan.

1. Not Tested by General Motors Corporation.

Table 16
Summary of Parr Bomb Tests
Fuel System Plastic Materials
1000 Hour Results

Percent Change in Material Property	CaRFG-T[1]	CaRFG-E[1]	CaRFG-LA	RFA[1]	ASTM-C
Polybutylene Terephthalate (PBT)					
Tensile Strength	-31%	-76%	-22%	-26%	-37%
Ultimate Elongation	-26%	-73%	-1%	-10%	-11%
Tensile Modulus	-14%	-9%	-15%	-19%	-26%
Izod Impact Strength	-30%	-86%	-17%	-20%	-11%
Volume	2.8%	3.8%	2.6%	3.0%	4.8%
Weight	1.6%	2.0%	1.4%	1.7%	2.8%
Polyphenylene Sulfide (PPS)					
Tensile Strength	-11%	-2%	-11%	-8%	-6%
Ultimate Elongation	-8%	4%	-26%	-4%	11%
Tensile Modulus	-3%	-4%	-3%	-3%	-8%
Izod Impact Strength	-9%	-5%	9%	-9%	9%
Volume	0.8%	1.2%	0.4%	1.0%	3.6%
Weight	0.5%	0.8%	0.2%	0.6%	2.2%

Source: General Motors Corporation. February 1996. *Bench Test for the Performance Subcommittee*. Detroit, Michigan.
1. At 500 hours test time, CaRFG and RFA test fuels switched to CaRFG-LA for balance of test.

Fuel System Elastomers. Results of the reflux tests are shown in Tables 17 and 18, at 500 hours and 1000 hours, respectively. Results of the Parr bomb tests are shown in Tables 19 and 20, for 500 hours and 1000 hours, respectively. (Test results are included in Appendix 6, Tables 10 through 13.)

The elastomer tests showed that the fluorocarbon VITON A and the Epichlorohydrin samples performance in the CaRFG blends was similar to the performance of these elastomers in RFA. Property changes in CaRFG-E were slightly greater than for the other CaRFG blends. Not all of the 1000 hour tests have been completed, but the switch to the lower aromatic content fuel CaRFG-LA has not produced major differences in the property changes. Some property changes reversed, while others continued to degrade with time when the fuel switch was made. The fluorosilicone samples showed somewhat greater property changes in the CaRFG blends.

Table 17
Summary of Reflux Tests
Fuel System Elastomers
500 Hour Results

Percent Change in Material Property	**CaRFG-T**	**CaRFG-E**	**CaRFG-LA**	**RFA**	**ASTM-C**
Fluorocarbon-VITON A					
Hardness	-12.1%	-17.3%	-13.8%	-10.3%	-14.4%
Ultimate Elongation	-13.6%	-7.1%	-13.8%	-20.8%	-29.6%
Tensile Strength	-30.2%	-35.1%	-28.6%	-25.1%	-37.7%
Volume	13.1%	14.3%	12.5%	11.5%	18.6%
Epichlorohydrin					
Hardness	-17.1%	-23.7%	-11.0%	-24.2%	-40.8%
Ultimate Elongation	-26.1%	-37.4%	-41.8%	-36.1%	-57.0%
Tensile Strength	-4.1%	-13.5%	-5.2%	-11.5%	-39.9%
Volume	12.3%	14.8%	7.5%	15.4%	28.1%
Fluorosilicone					
Hardness	-23%	-28.6%	-23.0%	-9.0%	-19.8%
Ultimate Elongation	-33.4%	-24.0%	-30.4%	-31.4%	-31.6%
Tensile Strength	-32.9%	-40.8%	-28.6%	-17.0%	-27.7%
Volume	20.6%	16.5%	17.2%	14.7%	19.2%
Nitrile					
Hardness	-9.7%	0.4%	7.4%	-25.7%	-13.4%
Ultimate Elongation	-30.0%	-27.1%	-17.0%	-59.4%	-42.4%
Tensile Strength	-12.6%	-12.1%	-2.0%	-69.3%	-17.2%
Volume	15.1%	7.5%	0.9%	21.2%	14.7%

Source: General Motors Corporation. February 1996. *Bench Test for the Performance Subcommittee*. Detroit, Michigan.

Table 18
Summary of Reflux Tests
Fuel System Elastomers
1000 Hour Results

Percent Change in Material Property	**CaRFG-T[1]**	**CaRFG-E[1]**	**CaRFG-LA**	**RFA[1]**	**ASTM-C**
Fluorocarbon-VITON A					
Hardness	-12.5%	-12.3%	-10.8%	-12.3%	-8.8%
Ultimate Elongation	-14.2%	-9.5%	-21.8%	-9.5%	-31.8%
Tensile Strength	-26.4%	-29.5%	-34.3%	-29.5%	-32.4%
Volume	12.8%	13.3%	12.1%	13.3%	10.4%
Epichlorohydrin					
Hardness	-11.0%	-2.2%	-5.9%	-8.7%	-6.4%
Ultimate Elongation	-41.4%	-41.0%	-45.1%	-38.3%	-41.0%
Tensile Strength	-10.9%	-10.3%	-13.9%	-14.2%	-9.1%
Volume	8.2%	2.4%	5.3%	5.8%	2.6%
Fluorosilicone					
Hardness	-0.206	-17.6%	-19.0%	-16.2%	-16.6%
Ultimate Elongation	-0.328	-37.3%	-28.8%	-38.2%	-27.3%
Tensile Strength	-0.276	-30.7%	-27.7%	-30.5%	-28.1%
Volume	0.178	17.9%	18.1%	20.5%	14.1%
Nitrile					
Hardness	10.6%	5.8%	7.3%	1.6%	6.5%
Ultimate Elongation	-29.6%	-23.9%	-21.1%	-58.0%	-33.8%
Tensile Strength	-9.1%	-8.0%	-3.3%	-54.4%	-3.3%
Volume	0.2%	-1.7%	-0.0%	-0.8%	-0.6%

Source: General Motors Corporation. February 1996. *Bench Test for the Performance Subcommittee* . Detroit, Michigan.

1. At 500 hours test time, CaRFG and RFA test fuels switched to CaRFG-LA for balance of test.

Table 19
Summary of Parr Bomb Tests
Fuel System Elastomers
500 Hour Results

Percent Change in Material Property	**CaRFG-T**	**CaRFG-E**	**CaRFG-LA**	**RFA**	**ASTM-C**
Fluorocarbon-VITON A					
Hardness	-13.7%	-18.8%	-12.9%	-13.3%	-18.0%
Ultimate Elongation	-4.7%	-13.1%	-14.3%	-13.6%	-17.2%
Tensile Strength	-32.0%	-44.8%	-34.6%	-29.4%	-38.7%
Volume	16.1%	20.0%	15.2%	15.1%	23.3%
Epichlorohydrin					
Hardness	-11.5%	-26.7%	-11.9%	-21.5%	-41.8%
Ultimate Elongation	-49.6%	-41.8%	-42.9%	-51.7%	-42.7%
Tensile Strength	-17.8%	-19.6%	-16.0%	-24.4%	-35.0%
Volume	8.1%	16.8%	8.0%	15.7%	32.0%
Fluorosilicone					
Hardness	-27.6%	-38.0%	-24.6%	-21.2%	-39.4%
Ultimate Elongation	-34.8%	-21.8%	-25.9%	-38.1%	-22.3%
Tensile Strength	-44.5%	-48.8%	-34.1%	-39.3%	-46.3%
Volume	24.8%	18.4%	18.4%	17.4%	23.6%
Nitrile					
Hardness	16.7%	-3.6%	16.4%	5.7%	-3.3%
Ultimate Elongation	-51.3%	-50.7%	-54.2%	-43.5%	-43.7%
Tensile Strength	-23.9%	-31.2%	-20.9%	-20.3%	-14.0%
Volume	0.4%	6.2%	-0.3%	4.5%	13.0%

Source: General Motors Corporation. February 1996. *Bench Test for the Performance Subcommittee*. Detroit, Michigan.

Table 20
Summary of Parr Bomb Tests
Fuel System Elastomers
1000 Hour Results

Percent Change in Material Property	CaRFG-T[1]	CaRFG-E[1]	CaRFG-LA	RFA[1]	ASTM-C
Fluorocarbon-VITON A					
Hardness	-12.9%	-14.9%	-11.2%	-10.8%	-12.5%
Ultimate Elongation	-21.5%	-19.0%	-21.0%	-21.2%	-15.0%
Tensile Strength	-37.8%	-40.7%	-34.6%	-36.2%	-34.2%
Volume	16.0%	16.4%	16.1%	16.8%	16.3%
Epichlorohydrin					
Hardness	-6.4%	-14.0%	-11.8%	-8.2%	-7.5%
Ultimate Elongation	-51.7%	-36.7%	-40.3%	-48.3%	-41.8%
Tensile Strength	-24.0%	-41.4%	-41.2%	-28.8%	-33.1%
Volume	7.2%	6.9%	8.6%	8.2%	6.3%
Fluorosilicone					
Hardness	-0.236	-24.8%	-22.2%	-22.8%	-35.8%
Ultimate Elongation	-0.292	-32.2%	-39.4%	-40.5%	-40.8%
Tensile Strength	-0.394	-40.1%	-43.8%	-43.6%	-58.1%
Volume	0.195	15.7%	19.3%	24.7%	27.7%
Nitrile					
Hardness	23.5%	22.8%	14.1%	25.1%	19.7%
Ultimate Elongation	-91.7%	-90.8%	-89.9%	-90.3%	-87.7%
Tensile Strength	-64.9%	-64.1%	-58.9%	-54.8%	-65.5%
Volume	-1.5%	-1.8%	-1.9%	-2.2%	-2.1%

Source: General Motors Corporation. February 1996. *Bench Test for the Performance Subcommittee*. Detroit, Michigan.

1. At 500 hours test time, CaRFG and RFA test fuels switched to CaRFG-LA for balance of test.

Only the nitrile elastomer samples showed degradation of properties great enough to be a cause for concern. However, a comparison of the nitrile test results with CaRFG blends and with RFA showed no major differences between these fuels, indicating no additional adverse impact of CaRFG blends on nitrile rubbers, relative to conventional gasolines.

D. Summary

The reflux tests of the fuel system filter and float material samples did not produce material property changes that would be a concern in vehicle applications typical for these materials. The CaRFG blends produced small property changes that were similar to the RFA and ASTM Reference Fuel C results.

This finding is also valid for the Parr bomb tests of the fuel system plastics, except for the performance of the PBT samples in the ethanol blend, CaRFG-E. The other PPS and PBT Parr bomb tests produced results similar to those observed in RFA and ASTM-C test fuels. These tests indicated that extended use of ethanol-containing gasoline blends may warrant further review of fuel system applications of PBT involving high temperatures and/or pressures. Similar results have been observed in other Parr bomb tests of PBT samples in ethanol-containing gasolines in the Delphi-E laboratories.

In the reflux and Parr bomb tests of fuel system elastomers, the 1000 hours reflux and Parr bomb tests showed little effect of the CaRFG blends on the fluorocarbon (VITON A) and epichlorohydrin samples, relative to RFA. ASTM Reference Fuel C tended to produce somewhat greater property changes for these two elastomers. The fluorosilicone samples exhibited larger property changes in the CaRFG blends relative to RFA at 500 hours, but these differences were not sufficient to warrant concern. The nitrile rubber samples did show large property changes in both the reflux and Parr bomb tests. The nitrile property changes of concern (primarily ultimate elongation and tensile strength) occurred in both CaRFG and RFA, in the more severe Parr bomb tests. In the less severe reflux tests, RFA tended to produce greater nitrile property changes than did the CaRFG bench test fuels.

Nitrile elastomers were used in older, carbureted fuel systems, but have been replaced by fluorocarbons (VITON's, e.g.) or other elastomers in more recent fuel system designs. Service part applications have also been upgraded. The design applications in which nitriles were used (mechanical fuel pump diaphragms, carburetor accelerator pump diaphragms and cups) began to disappear in the early to mid-1980 model years, with the introduction of electronic fuel injection systems and in-tank, electric fuel pumps. As noted in preliminary discussions of the GM bench test results with the Performance Subcommittee, the nitrile results indicate that the nitrile rubbers may be unsatisfactory at high age and/or mileages, in the carbureted vehicle designs in which these materials were used. (See Appendix 6.)

Overall, the fuel system materials evaluated in the GM bench tests did not exhibit unusual or unexpected performance in the CaRFG blends, relative to extensive test experience at the Delphi-E laboratories with non-oxygenated and oxygenated gasolines. The performance of "used" fuel system plastics or elastomers, simulated by the fuel switch at 500 hours of testing to the low aromatic CaRFG blend, also was satisfactory, with no noticeable alteration of the property change trends.

CHAPTER VI

HARLEY-DAVIDSON TEST PROGRAM

A. Introduction

Harley-Davidson expressed concerns about reformulated fuels following the introduction of federal reformulated gasoline. At the ARB's suggestion, they initiated a comprehensive test program. They tested on-road motorcycles at their facilities located in Alabama and Milwaukee, Wisconsin. Their test program included evaluations of performance, durability, emissions, and fuel economy of motorcycles operating with CaRFG. (See Appendix 7 for more details on the test program.)

B. Harley-Davidson Motor Company Test Program

Harley-Davidson selected 11 motorcycles for testing to represent a cross-section of engine families, models, and mileage levels. Table 21 lists the engines used in the test program with the model year, the fuel management system, number of miles on the engine at the start of the program, and the mileage accumulation during testing. As shown, the test fleet consisted of a mix of low and high mileage vehicles, with initial odometer readings varying from 1,052 to 64,872 miles.

1. Performance Testing

Test drivers evaluated the performance of motorcycles while accumulating between approximately 5,000 to 10,000 miles. The vehicles were operated over 3 different duty cycles designed to represent a full range of driving conditions. Each duty cycle is described below.

- General Durability Course: A group of courses on public roads that combines city driving, secondary roads and Interstate driving. Each course is approximately 100 miles long.

- Sport Course: A 90 mile course on public roads which consists primarily of hills and curves over a mountain route.

- Tri-Course: A 50 mile course primarily on public roads which includes a combination of rough road surfaces, frequent stops and starts, hard braking, a wide range of engine rpm, and an aggressive riding style.

The driveability and startability of the engines were documented by the drivers. Periodic reports were collected on the length of time to start the engine, frequency of engine misfires, general vehicle performance and any unusual occurrences.

A detailed evaluation of acceleration was performed with vehicles operating on a chassis dynamometer. Data were collected for 3 of the motorcycles.

Table 21
Harley-Davidson Test Engines

Model	Year	Fuel System	Displacement (cc)	Initial Odometer	Accum. Miles	Duty Cycle
Sportster	96	C	1200	10,285	10,124	General
Sportster	96	C	1200	7,614	9,820	Sport
Ultra Classic Electra Glide	95	FI	1340	37,607	6,206	General
Ultra Classic Electra Glide	97	FI	1340	1,052	5,103	General
Standard Electra Glide	97	C	1340	5,030	5,164	Tri Course
Dyna Low Rider	95	C	1340	64,872	2,211	Tri Course
Dyna Super Glide	96	C	1340	24,064	5,936	Tri Course
Dyna Wide Glide	96	C	1340	7,524	9,476	General
Heritage	95	C	1340	5,592	---	Lab FET
Ultra Classic Electra Glide	95	FI	1340	10,445	---	Lab FET
Dyna Wide Glide	96	C	1340	29,607	---	Accel. Perf.

Source: Harley Davidson. September 20, 1995. *Harley Davidson Engineering Report: Alternate Fuels Compatibility.* Lincoln, Alabama.

2. Durability Testing

Two motorcycles accumulated approximately 10,000 miles on the Sport and General Course to evaluate engine durability. The vehicles selected for durability testing had accumulated approximately 7,500 miles prior to testing with CaRFG. After mileage accumulation, both engines were visually inspected to document the general conditions and appearance of cylinder head, cylinder, piston and valves. Specific data were recorded for oil temperature, spark plug temperature, and condition throughout the duration of the test. The effect of fuel on fuel tank finishes and decals was also observed.

3. Fuel Economy

On-road testing for fuel economy was conducted according to Society of Automotive Engineers J1082 Test Procedures (January. 1989). Test driving was performed on the Talladega Speedway located in Alabama. Including accelerations, decelerations, and stops, the following 3 driving cycles were evaluated:

- Urban Driving Cycle: varying speeds from 0 to 30 mph.
- Suburban Driving Cycle: varying speeds from 0 to 50 mph.
- Interstate Driving Cycle: two primary speeds, 55 and 70 mph.

Fuel economy of motorcycles operating with CaRFG was also evaluated in the laboratory with the vehicles operating on chassis dynamometer. Two vehicles were studied according to the Society of Automotive Engineers J1082 Test Procedures (January 1989).

4. Emissions Testing

To assess the effect of CaRFG on emission levels for these motorcycles, exhaust emissions were measured at the beginning and end of mileage accumulation. Testing of 2 vehicles was conducted on chassis dynamometer and according to U.S. EPA test procedures (CFR 40, Subpart F).

C. Results of the Harley-Davidson Motor Company Test Program

The Harley-Davidson Motor Company findings are summarized in the following discussion. (Appendix 7 contains more details on the Harley-Davidson Motor company test report). The results are relative to conventional gasoline for engine performance and durability and relative to indolene gasoline for fuel economy and emissions.

1. Engine Performance

Driveability was not affected by CaRFG. In some cases, an increase in engine misfires was noted, possibly due to a vehicle's "lean calibration" in combination with oxygenated gasoline. In other cases, drivers noted improved driveability and increased power, possibly due to the vehicle's "fuel rich calibration" combined with the enleanment effect of oxygenated fuels. Furthermore, startability, under summer weather conditions, was unaffected by CaRFG, and no changes in acceleration performance were noted by the vehicle riders.

2. Engine Durability

Engine durability (engine wear) was unaffected by CaRFG for the limited duration of the test program. Clean intake ports were maintained with the use of CaRFG and significantly lower carbon build-ups were noted on the intake valve stems. Furthermore, the CaRFG appeared to remove built-up carbon deposits in the intake port. Carbon build-up was typical on other parts of the engine. Paint finish and decals were unaffected by either the commercially available gasoline or CaRFG.

3. Fuel Economy

The testing showed that fuel economy is between 1 to 4 miles per gallon lower with CaRFG than with indolene gasoline (3-13%). However, a smaller amount of fuel economy decrease was noted with fuel injected vehicles, suggesting that more precise fuel control reduces variability.

4. Emissions Testing

The results of the emissions testing showed that the use of CaRFG reduced carbon monoxide emissions between 1 to 3 gm/km (8-25%). Hydrocarbon emissions were reduced slightly, and oxides of nitrogen were unaffected by CaRFG.

CHAPTER VII

HOLLEY PERFORMANCE PRODUCTS INCORPORATED TEST PROGRAM

A. Introduction

This chapter discusses the bench tests that Holley Performance Products conducted on power valves and other elastomers and components using the On-Road test fuel. (Appendix 8 provides the details on the Holley Performance Products test program and also discusses Holley's analysis of the parts that failed during the On-Road test program.)

B. Bench Testing

Holley tested several power valves and elastomer components used in Holley products with the On-Road test fuel.

Thirty Holley power valves were tested at 85 to 90 degrees Fahrenheit. To simulate a vehicle in operation, the tests were run over 500,000 cycles, which represent over 5 million miles traveled, over a 37 day period. Once completed, the power valves were checked for leaks and durability and functionality at the manufacturing facility. In the soak test, various samples of elastomers and components used in Holley products were soaked for 85 days in CaRFG test fuel and conventional fuel. Holley examined the materials for degradation, functionality, swelling, flexibility and compressibility. Table 22 lists the materials and components tested.

C. Results of the Holley Test Program

All 30 power valves and the other elastomers components passed the tests. The soak test indicated that there was very little difference between the CaRFG test fuel and the conventional fuel. When compared, the parts soaked in the test fuel and the conventional fuel were very similar. The needle and seat assemblies also passed the leak tests.

In its report Holley Performance Products Incorporated concluded: “As a result of contact and operation tests, it has been found that California Phase 2 reformulated gas has no detrimental effect on Holley fuel handling products.”

Table 22
Holley Performance Products Elastomers
Tested in the Soak Test

Material	**Description**	**Part Number**
Viton	O-ring Seal	27R 762
Buna-N	O-ring Seal (transfer tube)	27R 109
Buna-N	O-ring Seal (transfer tube)	27R 350
Chemprene	Power Valve Diaphragm	25R 99
DuPont BN-0058 & CRS	Pump Diaphragm and Washer Assembly	35R 342A
GFLT on nomex or nylon & CRS	Pump Diaphragm and Washer Assembly	35R 1936A
Buna-N	O-ring Seal	27R 148
Brass and Viton	Needle and Seat Assembly	18R 292A
Brass and Buna-N	Needle and Seat Assembly	18R 297A

Source: "Reformulated Gasoline: Its effect on Holley Products." Engineering Report 95-014. Holley Performance Products Incorported. December 14, 1995 .

CHAPTER VIII

NISSAN MOTOR COMPANY TEST PROGRAM

A. Introduction

The Nissan Motor Company (Nissan) performed a study to compare how conventional gasoline and a CaRFG fuel affected the formation of deposits on the intake valves and combustion chambers.

B. Nissan Deposit Formation Test Program

Nissan conducted in-use testing in California on two vehicles to study the deposit formation on valves and in the combustion chamber. The test program used the base model Nissan Sentra 4 cylinder, spark ignition, internal combustion engine certified to meet California emission standards. In particular, the test examined the effects of the test fuel on the intake and exhaust valves and piston heads after 30,000 miles of driving. Specifically, vehicle 1, burning conventional fuel, was driven 32,141 miles while vehicle 2, burning the reformulated gasoline, was driven 31,678 miles. Table 23 shows the vehicle engine specifications of the test vehicles.

In addition to the in-use test, Nissan performed a 100 hour bench test on a 1.6 liter dual overhead cam engine using the Intake Valve Deposit (IVD) generation cycle. For IVD test mode, the engine oil used was STD 5W-30.

Table 23
Vehicle Engine Specifications

Base Model	MY1993 Sentra (B13) California
Engine	GA16 -- L4 1.6L 4CYL DOHC Fuel System: Multi-point EFI with EGR
Catalyst	Close-coupled catalyst, underfloor catalyst
O2 Sensor	ZrO2

Source: Nissan Motor Company. September 19, 1995. *Status report presented to the Performance Subcommittee.* Sacramento, California.

Each of the fuels contained the same additives. The fuel properties are shown in Table 24.

Table 24
Nissan Test Fuels

Fuel Parameter	RFG	Conventional
RVP (at 100 °F), psi	6.43	9.85
Sulfur, ppmw	37	232
Benzene, vol%	0.9	1.8
Aromatics, vol%	22.0	31.1
Olefins, vol%	4.3	7.2
MTBE, vol%	12.8	0.0
Gum Content, mg/100ml - Unwashed	2.4	2.0
Gum Content, mg/100ml - Washed	0.4	1.4
T50, F	200	190
T90, F	301	292

Source: Nissan Motor Company. September 19, 1995. *Status report presented to the Performance Subcommittee*. Sacramento, California.

C. Results of the Nissan Test Program

The Nissan deposit formation test data indicate no adverse formation of deposits from the use of CaRFG . The preliminary analyses indicate that there were apparently less intake valve deposits and no changes in the combustion chamber deposits. Further, there were no material compatibility issues raised during the test program.

The Nissan Reformulated Gasoline Test Program indicates that the CaRFG test fuel used by Nissan burns cleaner than the pre-1995 conventional fuel. In particular, the test results indicate the following:

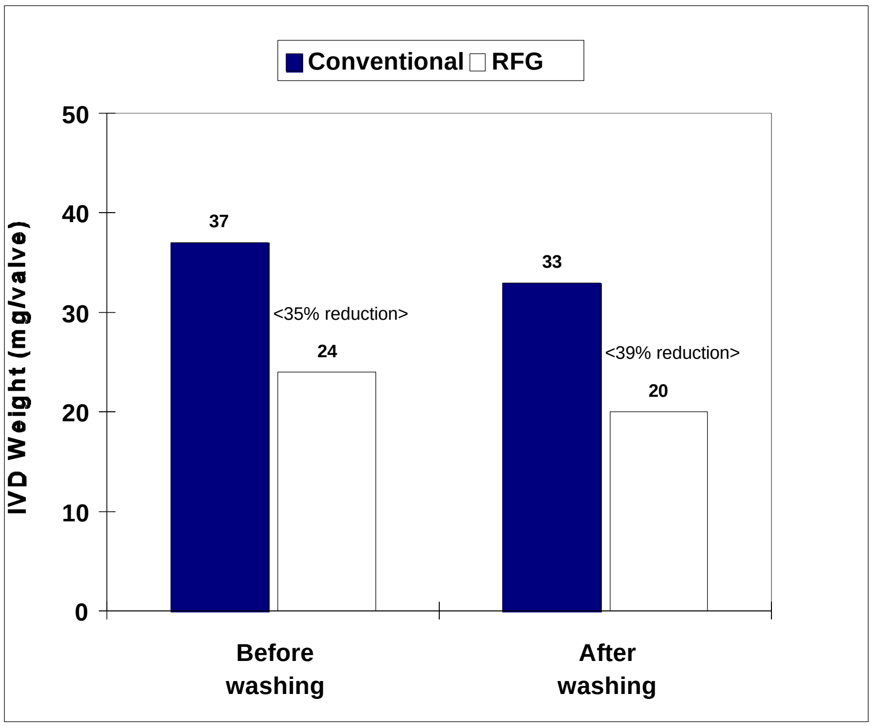
1) Intake valve deposit formation with reformulated gasoline is less than with conventional gasoline.

2) Combustion chamber deposit formation with the reformulated gasoline is the same as with conventional gasoline.

3) Under the test conditions, there were no differences in the deterioration of fuel system components between the reformulated gasoline and the conventional gasoline.

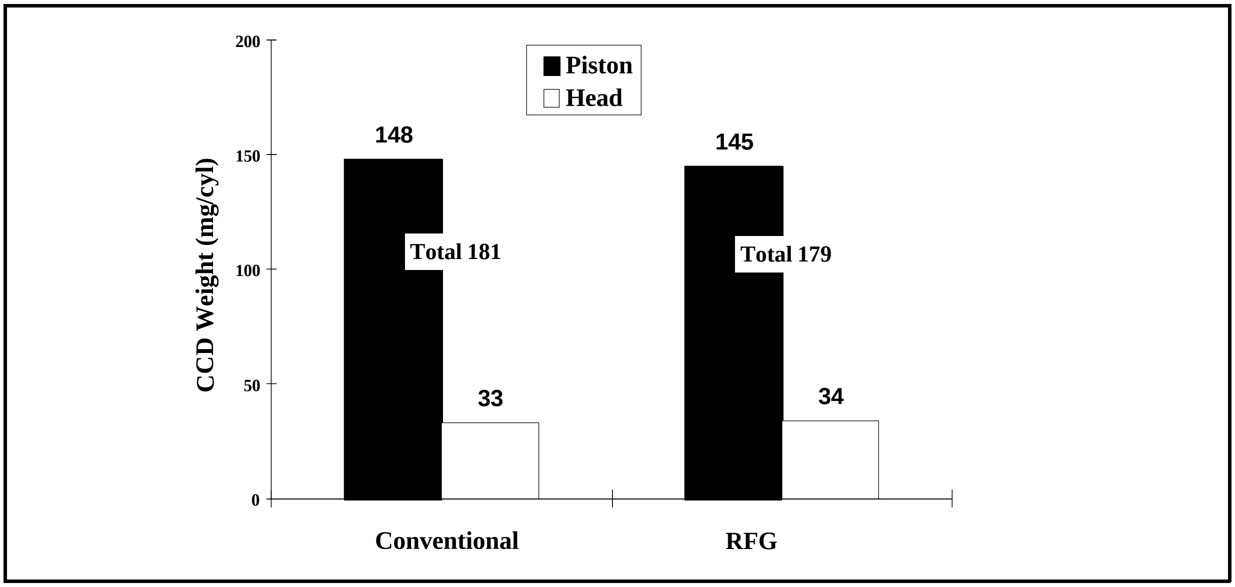
For the in-use test, the combustion of the test fuel decreased the intake valve deposits about 35 to 39 percent (See Figure 2). Also, the combustion chamber deposit formation for both fuels was about the same (See Figure 3). The Nissan Reformulated Gasoline Test Program was presented to the Performance Subcommittee on September 19, 1995. (See Appendix 9 for the study.)

Figure 2
Intake Valve Deposits Determined from In-Use Testing



Source: Nissan Motor Company. September 19, 1995. *Status report presented to the Performance Subcommittee* . Sacramento, California.

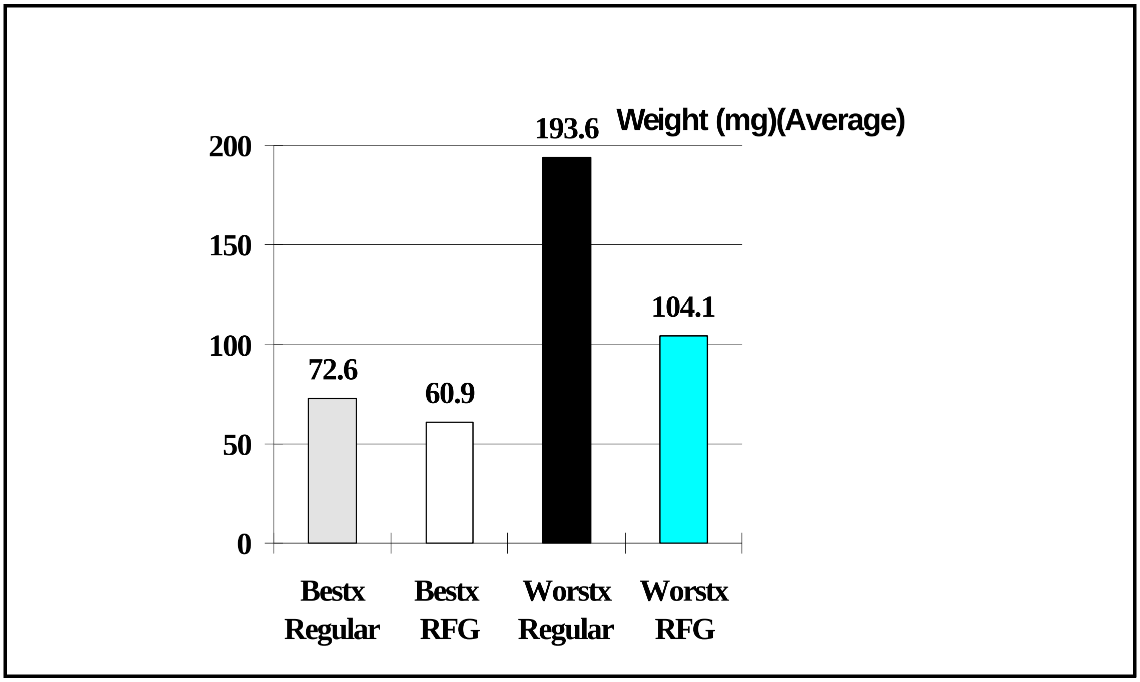
Figure 3
Combustion Chamber Deposits Determined from In-use Testing



Source: Nissan Motor Company. September 19, 1995. *Status report presented to the Performance Subcommittee*. Sacramento, California.

For the bench test, comparing the intake valve deposit formation after combustion for the conventional to the reformulated gasoline also showed a valve deposit formation decrease (see Figure 4).

Figure 4
Average Intake Valve Deposits Determined from Bench Testing



Source: Nissan Motor Company. September 19, 1995. *Status report presented to the Performance Subcommittee*. Sacramento, California.

CHAPTER IX

TEXACO TEST PROGRAMS

A. Introduction

Texaco conducted 2 limited test programs to evaluate the performance of test fuels, on fuel system components using very low levels of aromatic hydrocarbons (5 to 10 percent by volume). As with the Chevron program, the Texaco test program used Texaco test fuels which met the CaRFG standards; however, the specifications for the Texaco test fuels differed very significantly from the Chevron and On-Road test fuels. (See Appendix 10 for details on test programs.)

B. Fleet Test Programs

1. Bakersfield, California Test Program

At its Bakersfield, California refinery, Texaco in cooperation with the ARB tested an in-plant fleet using test fuels containing 5 percent and 10 percent aromatic hydrocarbon levels. The levels of these fuels are 83 percent and 63, respectively, below the 30 percent maximum level allowed by the CaRFG cap limit. The Texaco test fuel was a blend of the ARB On-Road test fuel used for the ARB test program and alkylate. The program tested the compatibility of fuel system components of vehicles "accustomed" to the high aromatic content fuels, typically 40 percent, when suddenly switched to very low aromatic fuels. The properties of the fuels are shown in Table 25.

Table 25
Texaco Test Fuel Properties
Bakersfield Vehicle Test Program

Fuel Component	Conventional Gasolines used Bakersfield Area	On-Road Test[1] Program Test Fuel	~10 vol% Aromatic Test Fuel	~5% vol% Aromatic Test Fuel
Sulfur, ppmw	2.1-16.3	53	18.2	13.3
Benzene, vol%	0.8	0.92	0.55	0.28
Oxygen, wt%	0.00	2.05	1.23	0.63
RVP, D-323	6.9-7.2	6.4	6.4	6.0
T50, D-86[1]	225-232	187	203	212
T90, D-86[2]	334-336	288	290	274
Aromatics, vol%	39.2-41.4	17.4	9.58	4.95
Olefins, vol%	0.44-0.62	7.86	4.50	2.82

Source: Texaco Refining and Marketing Inc. June-July 1995. Draft Report. Table 2. *CARB Phase 2 Low Aromatics Reformulated Gasoline Test, Bakersfield Refinery Fleet*.

1. Texaco tested the On-Road fuel at its laboratory in Bakersfield.
2. ASTM D-86 Temperature repeatability is +/- 19 °F.

Table 26 shows a summary of vehicles by model year and odometer readings for both the test and control fleets.

Table 26
Texaco Bakersfield Test Fleet
by Model Year and Odometer Reading

Odometer	<1981	1981-84	1985-89	>89	Total
<50,000	1	3	15	7	26
50,000-100,000	0	0	0	1	1
100,000-150,000	0	0	0	0	0
>150,000	0	0	0	0	0

Source: Texaco Refining and Marketing Inc. June-July 1995. Draft Report. Table 2. *CARB Phase 2 Low Aromatics Reformulated Gasoline Test, Bakersfield Refinery Fleet*.

The fleet tested comprised 27 refinery vehicles, of which 14 vehicles operated on 10 percent aromatic fuel for 2 weeks and were then switched to 5 percent for an additional 2 weeks. The other 13 vehicles remained in operation on conventional gasoline for the first 2 weeks and were then switched to 5 percent aromatic hydrocarbon fuel for the final 2 weeks.

Table 27
Testing Timeline for Texaco-Bakersfield Fleet [1]

	Group 1	Group 2
Prior to Test	~40% aromatic conventional fuel	~40% aromatic conventional fuel
Test Period 1 (6/13-6/28)	10% aromatic fuel	40% aromatic fuel
Test Period 2 (6/28-7/12)	5% aromatic fuel	5% aromatic fuel
End of Test	~40% aromatic conventional fuel	~40% aromatic conventional fuel

Source: Texaco Refining and Marketing Inc. October 3, 1995. Draft Report. *CARB Phase 2 Low Aromatics Reformulated Gasoline Test, Bakersfield Refinery Fleet*. Bakersfield, California.

1. Initial and final inspections were conducted for both vehicle groups. However, an additional inspection was conducted prior to test period 2 for the group 1 fleet.

The vehicles are domestic models that operate primarily within the Bakersfield refinery; thus, they are exposed to the severe climate at a refinery, including heat and dust. In addition, these vehicles make short trips with a significant amount of stop and go driving. Interviews of the drivers of the test fleet indicate that prior to the test program they used regular grade fuel, which based on the data in Table 25, contains about 40% aromatics. The sequence of testing and the program time line is shown in Table 27.

2. Beacon, New York Test Program

The Beacon test program was designed to test the effects of low aromatic gasoline on elastomer fuel system components during typical consumer service. The vehicles in the program were operated by their owners in day-to-day service during the test.

The test comprised 41 vehicles ranging from 1965 to 1992 model years for passenger cars and light and medium duty trucks in 4 technology classes. Each vehicle in the fleet was operated on 3 fuels: a commercially available fuel (“break in” fuel) with an aromatic hydrocarbon concentration of about 35% volume, a very low aromatic fuel containing a 6% volume concentration, and a high aromatic fuel containing a 49% volume concentration. The fuel specifications are listed in Table 28.

Table 28
Texaco Test Fuels Parameters
Beacon, NewYork Vehicle Test Program

Fuel Parameter	"Break in" Fuel	Low Aromatic Fuel	High Aromatic Fuel
Aromatics, vol%	35	6	49
Benzene, vol%	0.65	0.07	0.34
RVP, psi	10.3	10.3	8.8
T50, °F	193	197	224
T90, °F	325	269	352
Sulfur, ppmw	112	86	79
Oxygen, wt%	2.7	2	0
Olefins, vol%	8.3	2.9	5

Source: Texaco Refining and Marketing Inc. Texaco R&D. October 22, 1995. *Texaco Presentation (Beacon Test Program)*.

All of the vehicles operated on the "break in" fuel for at least 3 weeks prior to the test. At the beginning of the test program, half of the vehicles were fueled with low aromatic fuel and the other half were fueled with high aromatic fuel. After 3 weeks the vehicles on low aromatic gasoline switched to high aromatic gasoline and the vehicles on high aromatic gasoline switched to low aromatic gasoline for an additional 3 weeks. An evaporative emissions test was conducted on the vehicles before, during and after the test program to test for any seal leaks.

C. Results of the Texaco Test Programs

1. Bakersfield, California Test Program Results

The vehicles in the Texaco program are operated at the refinery where they make short trips under stop-and-go conditions. As a result, the vehicles have very low mileage for their ages. However, they are subjected to severe operating conditions and climate, which are assumed to have led to an unusually high degree of "wear and tear" for the number of miles accumulated. The inspections of the vehicles were done by ARB inspectors.

Table 29 provides the vehicle descriptions and test information at the time the parts were replaced. In some cases multiple incidents were recorded for a vehicle. A summary of all incidents of fuel system problems that were reported is available in Texaco's report.

Table 29
Vehicles with Parts Replacements During Test Program

Make/Model	Model/Year	Odometer	Test Fuel[1]	Part
Dodge/Dakota	1987	41,006	5%	Fuel pump
Ford/F-250	1990	54,671	5%	Fuel pump[2]
Dodge/Dakota	1987	35,601	5%	Fuel pump
Ford/F-350	1987	25,397	5%	Carburetor
Dodge/Ram 150	1983	23,492	5%	Carburetor
Ford/F-250	1990	54,671	5%	Fill Pipe Hose[2]
Ford/F-350	1974	28,732	10%	Hose[3]
Ford/F-350	1974	28,922	10%	Hose[3]
Dodge Dakota	1987	42,251	10%	Other
Ford/F-150	1983	38,414	5%	Other

Source: Texaco Refining and Marketing Inc. June-July 1995. October 3, 1995. Draft Report.
1. Aromatic hydrocarbon content of the fuel in use when failure occurred.
2. = same vehicle; Ford Motor Company analyzed the fuel pump and reported that it failed due to unusually high wear caused by fuel contaminants. (Appendix 11, Part One).
3. = same vehicle.

2. Beacon, New York Test Program Results

Texaco's Beacon, New York testing resulted in 8 incidents reported for 7 vehicles. Upon further review, Texaco's Research and Development staff judged that 3 of the fuel related incidents may be attributable, at least in part, to gasoline with low aromatics concentration. Elastomer component repairs were necessary for 3 vehicles using the 6% aromatics fuel. These vehicles are listed in Table 30.

Table 30
Incidents in the Texaco Beacon Test Program

Make and Model	Model Year	Odometer	Incident Description
Chevrolet/Chevelle	1968	99,084	Accelerator pump malfunction
Plymouth Duster	1971	108,945	Accelerator pump leak
Ford F-250	1987	75,800	Increased evaporative emissions at accelerator pump

Source: Texaco Refining and Marketing Inc. Texaco R&D. (Beacon, N.Y.) Report, *ARB Phase 2 Low Aromatics Reformulated Gasoline Test*.

D. Discussion of Results

1. Results

The results of the 2 Texaco limited studies indicate that a switch from high to very low aromatic fuels might accelerate the failure of some fuel system components (e.g. seals and elastomers) in older, high mileage or extreme service vehicles. The ARB staff independently evaluated proprietary refinery data and the California gasoline distribution system. This evaluation indicates that even if very low aromatics are produced, commingling in the distribution system and dilution in the vehicle tank should dampen gasoline property changes so that consumers should not experience property variations nearly as wide as those evaluated in the Texaco programs. (For a discussion of incident data, see Appendix 11 for Letter from J. M Kulaowski to Dean Simeroth, November 2, 1995.)

2. Discussion of Fleet Differences

Both test fleets used the same type of extremely low aromatic test fuel; however, the operating conditions and use of the vehicles in Bakersfield and Beacon vary significantly. The Bakersfield fleet operated in a severe duty environment while the vehicles in the Beacon fleet are owned and operated by consumers. These differences may account for a higher rate of incidents in the Bakersfield fleet compared to the Beacon fleet.

CHAPTER X

UNITED STATES DEPARTMENT OF ENERGY
LONG TERM MILEAGE ACCUMULATION TEST PROGRAM

A. Introduction

The objective of the Department of Energy (DOE) sponsored test program was to evaluate the long term effect of CaRFG use on vehicle operation. The program studied the effects of converting vehicles that were operated on conventional gasoline to CaRFG. The program also monitored fuel economy as part of the test. This chapter summarizes the DOE long-term on-road test program; for more detailed information refer to the status report provided by the National Institute for Petroleum and Energy Research (NIPER) in Appendix 12.

B. Background

The fuels used in the test program were a Federal Reformulated Gasoline (RFG) for baseline tests which was purchased in Texas and the summer CaRFG test fuel used in the On-Road test program. A list of the fuels parameters are listed in Table 31.

Table 31
DOE Test Fuels' Parameters

Fuel Parameter	CaRFG On-Road Test Fuel (Summer)	Federal RFG
Aromatics, vol%	19.8	25.2
Benzene, vol%	0.94	1.25
Olefins, vol%	4.4	17.0
Oxygen, wt%	2.0[1]	2.2[2]
RVP, psi	7.0	6.2
Sulfur, ppmw	44	275
T50, °F	189	198
T90, °F	297	353

Source: National Institute for Petroleum and Energy Research. February 1996. *Emissions Performance of California Phase 2 Reformulated Gasoline (Status Report)*. Bartlesville, Oklahoma.

1. Calculated as 2.0 wt% from 11.2 vol% MTBE.
2. Calculated as 2.2 wt% from 12.4 vol% MTBE.

The fleet tested comprised 5 in-use 1994 model year California vehicles that had an initial odometer reading of about 20,000 miles. The vehicles in this test program were selected to represent vehicles commonly used in California. A list of the vehicles in this test program is listed in Table 32.

Table 32
Vehicles in the DOE Test Program

Vehicle	Model Year	Displacement (Liters)	Mileage
Toyota Camry	1994	2.2	18,100
Honda Accord	1994	2.2	20,400
Ford Taurus	1994	3.0	22,000
Chevy Lumina	1994	3.1	29,500
Nissan Maxima	1994	3.0	21,500

Source: National Institute for Petroleum and Energy Research. February 1996. *Emissions Performance of California Phase 2 Reformulated Gasoline (Status Report)*. Bartlesville, Oklahoma.

The vehicles were operated with CaRFG for 30,000 miles. The mileage was accumulated over-the-road on an accelerated NIPER driving cycle, which incorporates a combination of typical city, suburban, and highway driving at 4 cycles per day (approximately 100 miles), with 1 hour soaks between cycles. Vehicle emissions and fuel economy were also measured using federal RFG before and after the test, and were measured using CaRFG at 2,000, 10,000, 20,000 and 30,000 miles.

C. Results

1. Performance

The 5 vehicles were monitored during the test program and no fuel related problems were experienced during the 30,000 mile accumulation test.

2. Fuel Economy

Based on gasoline property values taken from NIPER's status report, the energy content of the federal RFG was 113,200 Btu/gal and for the CaRFG it was 110,350 Btu/gal. That represents 2.5 percent energy content reduction when compared to the federal RFG. The 5 vehicles used in this test program were tested over 2 dynamometer cycles and the average of relative fuel economy decreases from federal RFG compared to CaRFG was 4 percent. While the NIPER test fuel meets federal RFG requirements, it probably does not represent an average federal RFG and thus produced a greater fuel economy effect than expected on average. Considering this information, the results do not represent a significant deviation from the fuel economy results in the On-Road test program.

PART THREE

CHAPTER I

INTRODUCTION

A. Introduction

In Part Three of this report, the off-road vehicles and equipment test programs are discussed. The objective of the test programs is to evaluate the compatibility, durability, and performance of California Reformulated Gasoline (CaRFG) with engines and fuel systems in off-road vehicles and equipment.

The Performance Subcommittee (Subcommittee) agreed that several different test programs were required to cover the variety of applications and design characteristics of off-road vehicles and equipment. To adequately represent the off-road population, 14 separate test programs were conducted and are referred to as the "off-road vehicles and equipment test program." Seven of the 14 test programs were sponsored by the Air Resources Board (ARB) in conjunction with the Subcommittee, and the remaining 7 test programs were sponsored by manufacturers.

B. Background

In California, there are approximately 6 million gasoline-powered off-road vehicles and equipment. The off-road fleet includes engines used in applications ranging from chain saws to ski boats and encompasses both 4 and 2 cycle engines. The off-road fleet consists of 7 major categories which are listed below in descending order of population in California:

- utility, lawn, and garden equipment
- pleasure craft and small marine engines
- off-road motorcycles and all terrain vehicles
- personal watercraft
- industrial and construction vehicles and equipment
- snowmobiles
- agricultural vehicles and equipment

The utility, lawn, and garden category dominates the off-road fleet with approximately 4.6 million units, or 77 percent of the total fleet. Pleasure craft and small marine engines represent the second largest segment with approximately 782,200 units or 13 percent of the total fleet. The remaining 5 categories account for less than 10 percent of the total fleet. (See Appendix 1 for more information on the California Off-Road fleet.)

C. Summary

It is estimated that the off-road vehicles and equipment logged an excess of 25,475 miles and 12,000 hours on CaRFG test fuel. Approximately 10,800 gallons of fuel were consumed by test engines. In the entire test program, 2 incidents were considered possibly fuel related, and one of those was reported on an engine using control fuel. Table 1 summarizes the fleets that participated in the test program.

D. Structure of the Part Three

Chapter II describes the design of the off-road test program.
Chapter III discusses the utility, lawn, and garden test programs.
Chapter IV discusses the pleasure craft and small marine engines test programs.
Chapter V discusses the personal watercraft test program.
Chapter VI discusses the industrial, construction, and agriculture equipment programs.
Chapter VII discusses the snowmobile test program.

Table 1
Off-Road Test Program Summary

Test Program	Number of Units	Incidents[1]	Hours/Miles	Amount of Fuel (gal)
Utility, Lawn, and Garden				
CSU Fresno	49	1	3,115 hrs	n/a[2]
Tecumseh	21	0	>1,150 hrs	864
Briggs & Stratton[3]	n/a	0	n/a	n/a
PPEMA[4]	12	0	n/a	405
Pleasure Craft Small Marine Engines				
Paradise Watercraft				
Test	7	0	858 hrs	4,363
Control	5	1	489 hrs	n/a
Lake Cachuma	95	0	6,000 hrs	3,572
Personal Watercraft				
Paradise Watercraft	11	0	964 hrs	750
Industrial, Construction, and Agricultural				
Caltrans	5	0	n/a	n/a
CSU Fresno	18	0	n/a	n/a
Snowmobiles				
Lake Tahoe Winter Sports Center	10	0	25,475 miles	850
Total	**233**	**2**	**12,000 hrs 25,475 miles**	**>10,800**

Source: California Air Resources Board. September 10, 1995. *Air Resources Board Oracle Database System/Reformulated Gasoline Project* . Sacramento, California.

1. Only incidents considered possibly fuel related have been listed (MAN classification)
2. N/a indicates data not available.
3. Briggs & Stratton test program details are confidential.
4. 2 of 5 companies have completed testing. Results from remaining companies are pending.

CHAPTER II

DESIGN OFF-ROAD VEHICLES AND EQUIPMENT TEST PROGRAMS

A. Introduction

In this chapter, the design of the ARB off-road and manufacturer sponsored off-road test programs is discussed, including the test protocol, vehicle and equipment selection, test fuels, sampling of the test fuel, data collection logs, and field activities.

B. Test Protocol

The Subcommittee endorsed the test protocol which defined the scope and design of the off-road test program. In addition, the test protocol included provisions for reporting incidents. (Appendix 2 contains the Off-Road Test Protocol and Test Plans.) The Subcommittee wanted diverse fleets which included:

(1) utility, lawn, and garden equipment,
(2) pleasure craft and small marine engines,
(3) off-road motorcycles and all-terrain vehicles,
(4) personal watercraft,
(5) industrial and construction vehicles and equipment,
(6) snowmobiles, and
(7) agricultural vehicles and equipment.

In designing the off-road program, the protocol characterized each category and established particular characteristics that should be included in a test fleet. These characteristics included, where applicable, engine configuration (2-stroke or 4-stroke), application, engine size (cubic centimeters (cc)), horsepower (hp), and duty cycle. Table 2 shows the in-use population of each category and breaks down the particular fleet characteristics that were important to establishing a representative test fleet. Table 2 also lists the actual test program fleet size.

The Subcommittee intended to test and evaluate off-road motorcycles and all-terrain vehicles. However, appropriate fleets were not available. Although off-road motorcycles were not tested, similar technologies found in snowmobiles and personal watercraft were tested and Harley-Davidson tested on-road motorcycles (See Part Two).

Table 2
Off-Road Vehicles and Equipment Population and Test Fleets

Fleet	**Total Population**	**Usage Splits (Model fleet)**	**Engine Configuration**	**Actual Test Fleet**
Utility, Lawn, and Garden	4,644,000	Mobile Stationary Hand-Held	4 stroke 2 stroke	30 52
Pleasure Craft and Marine Engines[1]	782,000	Inboard Outboard	4 stroke 2 stroke	1 107
Off-Road Motorcycles & All Terrain Vehicles[2]	299,000	Off-Road All Terrain Vehicle	4 stroke 2 stroke	0
Personal Watercraft	151,000	Sport Performance Touring	2 stroke	11
Industrial and Construction	70,000	Generators Forklifts Other Forklifts	4 stroke 2 stroke	18
Agricultural	13,000	25-40 hp 41-100 hp	4 stroke 2 stroke	2
Snowmobiles	14,000	Sport Performance Utility	2 stroke	10

Source: Booz-Allen & Hamilton Inc. January 1992. *Off-Road Mobile Equipment Emission Inventory Estimate*. Los Angeles, California.
California Department of Motor Vehicles. December 1992. Registration Records.
Motorcycle Industry Council. 1992. Motorcycle Statistical Annual.
California Air Resources Board. February 10, 1995. Sacramento, California.

1. Actual test fleet includes vehicles and equipment using test fuel (103) and conventional fuel (5).
2. Population number includes Off-Road Motorcycles and All Terrain Vehicles but does not include dual purpose motorcycles.

1. Vehicle and Equipment Selection of Off-Road Test Programs

To ensure a comprehensive program, the test protocol required that the fleets meet certain criteria. Specifically, the fleets had to have a central fueling station, uniform control, and a defined maintenance program. Various fleet operators were solicited throughout California to participate in the off-road test program and the following agreed to participate:

- California State University, Fresno (CSU Fresno)
- California Department of Transportation (Caltrans)

- Lake Cachuma Boat Rentals
- Lake Tahoe Winter Sports Center
- Paradise Watercraft Boat Rentals and South Shore Parasailing (Paradise Watercraft)

These 5 participants conducted 7 test programs. The CSU Fresno and Paradise Watercraft fleets conducted test programs covering 2 categories of off-road vehicles and equipment.

A Memorandum of Understanding (MOU) between the ARB and the owners of the test vehicles and equipment was established to agree upon policy issues. The MOU addressed the following:

- fuel supply
- data collection and reporting
- technical support
- performance evaluation
- program schedule and reporting

For each fleet, the MOU included a list of the vehicles and equipment expected to participate in the test program and a test plan outlining the specific tasks of the fleet operator and ARB staff. Except for the Paradise Watercraft Marine engine test program, the off-road fleet did not have control fleets.

2. Vehicle and Equipment Selection of Manufacturers' Test Programs

To supplement the off-road test program, utility, lawn, and garden equipment manufacturers also tested CaRFG independently. The following is a list of the participating companies:

- Briggs and Stratton Corporation
- Tecumseh Products Company
- Member companies of the Portable Power Equipment Manufacturer Association (PPEMA)

The manufacturer-sponsored test programs included bench-testing for durability, and in some programs, material compatibility, field, and emission testing.

C. Description of Fuels

The Subcommittee established the test fuel specifications to resemble the typical values of complying CaRFG reaching the consumer. The ARB staff contracted with Phillips 66 Chemical Company to produce the test fuel, given the 8 specifications set by the Subcommittee. (See Part One for a detailed description of the test fuels.) The off-road test fuel meets the same fuel specifications as the On-Road test fuel. However, for the manufacturer sponsored test programs, CaRFG certification fuel was used. (Appendix 3 contains the fuel specifications.)

1. Sampling

The fuel used in the off-road test program was sampled for property analyses according to the sampling protocol outlined in Part One. In general, the sampling protocol called for samples to be taken from the rail cars, each compartment of the cargo tank trucks, and the fuel storage tank at each test site. Normally, 2 samples were taken for each sampling event, and the 1 liter sample containers were labeled with pre-written sample labels and mailed to ARB's Monitoring and Laboratory Division for analysis.

Samples of conventional fuel were also taken from the Paradise Watercraft control site twice. The fuel was analyzed by Oronite, Division of Chevron. (Appendix 4 includes these test results).

D. Data Collection Logs

The data collection logs were designed to accommodate the off-road vehicles and equipment, including variations in duty cycles or fleet operating procedures. Data collected included equipment descriptions, inspection data, and incident data. (See Appendix 5 for a copy of the data sheets)

1. Description Logs

The description logs were used to record the fleet name, description of equipment, manufacturer, make, model year, number or hours of operation or miles at the start of the program, engine type, fuel system type, operator, and supervisor. Additionally, the form was used to log historical fuel system repairs.

2. Inspection Logs

At the onset of the program, a visual inspection was performed to establish the condition of the vehicle and equipment before testing. Follow-up and final inspections were also performed. Inspection logs were used to document the condition of fuel system components and to note any difficulties in starting or running conditions. In addition, the logs were designed to document any seeps or leaks from fuel system components.

3. Incident Logs

Incident logs were used to record unusual performance or repair events. The Subcommittee defined an incident as a performance problem or repair occurrence which could have been influenced or caused by the fuel.

Once the incident log was filled out, the maintenance personnel collected parts for the ARB and the engine manufacturer to inspect. Some parts were returned to the engine manufacturer for analysis. From a review of the incident log, repair orders, and analysis data, the incident was defined as fuel related, possibly fuel related, or not fuel related. Based on the findings of the engine manufacturer, a 3 letter code was assigned to each incident using the same coding system as the On-Road test program. (See Appendix 24 and 25 of Part One for more details).

4. Historical Data

The fleet operators were asked to provide historical repair records to establish a baseline of repairs. The CSU Fresno was the only fleet that provided historical repair data.

5. Field Activities

To assess and monitor the test program, the fleet managers were contacted regularly to discuss vehicle and equipment condition and performance characteristics. In addition, the fleets were visited every 2 weeks to gather information on the performance and compatibility of the test fuel. During these visits, incidents were investigated, fuel sampling procedures were reviewed, and operator input was recorded.

CHAPTER III

UTILITY, LAWN, AND GARDEN TEST PROGRAMS

A. Introduction

This chapter discusses the utility, lawn, and garden test programs by CSU Fresno, Tecumseh Products Company, Briggs & Stratton Corporation, and PPEMA member companies.

B. Background

This category includes 4-stroke and 2-stroke engines with either 1 or 2 cylinders. Depending on their application, the engine designs have either a horizontal or vertical crankshaft and an overhead or side valve. The 4-stroke engines include equipment such as lawn mowers while 2-stroke engines include hand-held equipment such as chain saws and weed trimmers. In general, utility, lawn, and garden equipment is rated at 25 horsepower or less. (See Appendix 6 for further information.)

C. Program Fleets

The off-road test program included testing at the CSU Fresno Grounds Division. To supplement the off-road test program, manufacturers of utility, lawn, and garden engines conducted independent testing. Tecumseh Products Company and Briggs & Stratton Corporation each conducted individual manufacturer sponsored test programs. In addition, member companies of the PPEMA conducted a round-robin test program which evaluated small hand-held equipment. These test programs provided a cross-section of manufacturers and a variety of test methods to evaluate CaRFG in utility, lawn, and garden equipment.

D. California State University, Fresno Grounds Division

1. Test Description

The CSU Fresno Grounds Division evaluated test fuel in utility, lawn, and garden equipment for 10 weeks. The fleet consisted of 42 units owned by CSU Fresno Grounds Divisions and 7 units loaned by members of PPEMA. These equipment have an extreme duty-cycle which is described as commercial landscaping. (Table 3 summarizes the inventory for CSU Fresno)

The equipment loaned by PPEMA were new units meeting California's new Phase 1 emission certification standards. PPEMA member companies were interested in gathering field test data from the use of their equipment in the CSU Fresno test program. The following identifies the equipment loaned to CSU Fresno:

Echo-Kioritz	backpack blower and chain saw
Andreas Stihl	backpack blower and weed trimmer
Homelite	weed trimmer
Poulan/Weed Eater	hand-held blower
Husqvarna	weed trimmer

(See Appendix 7 for more details on the PPEMA equipment.)

Table 3
CSU Fresno Grounds Division
Equipment Inventory and Hours of Use

Equipment (Engine Manufacturer)	**Number of Units**[1]	**Total Estimated Hours**
Blowers (Echo, Stihl, Poulan)	11	600
Chain saws (Stihl, Echo)	2	260
Edgers (Honda, Echo)	11	660
Hedge Trimmers (Echo)	8	720
Weed Trimmers (Echo, Homelite, Husqvarna, Stihl)	13	825
Tree Trimmer (Power Pruner)	1	40
Lawn Mowers (Jacobsen, Toro, Smithco)	3	10
Total	**49**	**3,115**

Source: California Air Resources Board. September 1, 1995. *California Air Resources Board Oracle Database Systems/Reformulated Gasoline Project.* Sacramento, California. California State University, Fresno. August 29, 1995. Conversation with Mr. Sal Genito, Department of Plant Operations. Fresno, California .

1. Number of units includes equipment loaned by PPEMA member companies.

The operators were asked to maintain hourly logs to monitor equipment use. The CSU Fresno fleet accumulated approximately 3,100 hours. The average number of hours logged by each unit was significantly larger than the hours logged by the average consumer. (Summary tables of data collected from the CSU Fresno program are in Appendix 8).

2. Inspections

The CSU Fresno fleet was inspected on 3 occasions, including initial and final inspections.

3. Results

No significant deterioration in the equipment was found from one inspection to the next. The operators and the fleet management did not note any increase in maintenance as a result of using CaRFG test fuel. Several users noted fuel economy losses. However, the changes in fuel economy were not documented and could not be quantified.

Incidents. During the program, 2 incidents were reported in the CSU Fresno test program. One incident involving a backpack blower was designated as possibly fuel-related but a normal repair considering the age and the condition of the unit. The backpack blower required a carburetor rebuild. The second incident involving a trimmer was defined as not fuel-related. (See Appendix 9 for Echo-Kioritz's letter of findings on this incident.)

E. Tecumseh Products Company

Tecumseh Products Company manufactures engines for utility, lawn, and garden equipment. For their test program, they selected typical 4-cycle engines for lawn mowers and garden tractors and 2-cycle engines for tillers.

1. Test Description

Tecumseh Products Company conducted field tests, engine reliability tests on engine stands, and component compatibility tests in the laboratory. The test fleet comprised 21 engines from their product line. Table 4 lists the engines tested and the corresponding test procedures. The lawn mowers were operated for 150 hours, garden tractors for 350 hours, and tillers for 75 hours, which are equivalent to the typical life span for these engine types. The Tecumseh Products Company conducted the testing at their New Holstein Operations Testing Facility in Wisconsin.

The majority of units in the California fleet have used conventional gasoline before using CaRFG. The Tecumseh test program was designed to simulate this fuel changeover. For the first half of the test program, half of the units operated on conventional gasoline and then operated on the CaRFG certification fuel for the final part of the test program. The remaining 50 percent of the units operated on the CaRFG certification fuel for the entire duration of the test.

2. Results

The Tecumseh Products Company test did not reveal any adverse effects with engine performance or compatibility. Some of the units that were run exclusively on CaRFG certification fuel exhibited a different type of combustion chamber deposit than deposits resulting in units run on conventional fuels. However, the formation of these carbon deposits was at a similar level to that of the other units.

Table 4
Tecumseh Test Procedures and Engines

Test Procedure	Model	Description	Number of Engines
Engine Stand Testing	TC200 VLV55 OHV16	Mini Tiller 2-Cycle Walk Behind Mower Murray 40" Riding Lawn Tractor	2 2 2
Field Testing	TC200 VLV55 OHV15/16	Mini Tiller 2-Cycle Walk Behind Mower Murray 42"/40" Riding Lawn Tractor	2 2 2
Engine Stand: Former Lines	LAV35 TVS105	Tiller Rotary Lawn Mower	1 1
Startability	VLV55 OHV16	Walk Behind Mower Murray 40" Riding Lawn Tractor	6 1
Total Number of Engines			21

Source: Tecumseh Products Company. November 11, 1995. *California Phase II Gasoline Evaluation with Small SI Engines Reliability Testing Report* . New Holstein, Wisconsin.

In their report, the Tecumseh Products Company further indicated that the “Results of compatibility tests show that the rubber and plastic parts have similar swelling characteristics in both the reformulated fuel and Reference Fuel B.” (The Tecumseh Products Company’s test plan and final report is contained in Appendix 10.)

F. Briggs & Stratton Corporation

Briggs & Stratton manufactures 4 cycle engines commonly used in lawn mowers, riding tractors, and other outdoor power equipment.

1. Test Description

Briggs & Stratton conducted testing of 4-cycle engines at their research and development center in Milwaukee, Wisconsin and their field testing facility in Fort Pierce, Florida.

2. Results

Briggs & Stratton has requested that the detailed results of their test program remain confidential. However, in a press release, Briggs & Stratton issued the following findings:

- Reformulated gasolines should have no significant effect on the operation of Briggs & Stratton 4-cycle engines commonly used in lawn mowers, riding tractors, and other outdoor power equipment.

- A significant number of hours were logged testing Briggs & Stratton engines with reformulated gasolines.

- Tests of 4-cycle engines revealed no significant problems that could be attributed to the reformulated gasolines.

(Appendix 11 contains the press release issued by Briggs & Stratton.)

G. Portable Power Equipment Manufacturers Association Round-Robin Test Program

PPEMA is a trade organization representing manufacturers of gasoline-powered chain saws, trimmers, brush cutters, blowers, cut-off saws, generators, and similar products. Participating companies are located around the world. As a continuation of PPEMA's evaluation of federal reformulated gasoline (federal RFG), member companies offered to test CaRFG. The PPEMA members conducted round-robin manufacturer testing of hand-held portable utility, lawn, and garden equipment such as chain saws, trimmers, and blowers.

The fuels used in the federal RFG test program were described as extreme blends of oxygenated reformulated gasoline. The 2 federal RFG test fuels were each blended with ethanol and had 8 and 15 Reid vapor pressure (RVP) respectively. All of the participating PPEMA member companies used the same CaRFG certification fuel. Table 5 lists the properties of the CaRFG and federal RFG test fuels used.

Table 5
Fuel Properties for Federal and CaRFG Test Fuels

Property	Federal RFG (Ethanol Blend)	Federal RFG (Ethanol Blend)	CaRFG Certification
RVP, psi	14.8	8.1	7.0
Aromatic content, vol.%	22.3	22.3	13.7
Olefinic content, vol. %	4.4	4.9	4.7
Sulfur content, ppm	40	40	39
Benzene content, vol. %	n/a	n/a	0.9
Oxygen, wt %	3.47 [1]	3.40 [1]	~2
T50, °F	175	209	209
T90, °F	293	294	300

Source: Howell Hydrocarbons & Chemicals Inc.. 1995. Product Information
1. Blended with Ethanol at 9.8% vol.

1. Test Procedures for PPEMA Equipment

The CaRFG test plans used by each participating company were based on a protocol developed by Poulan/Weed Eater for the federal RFG testing program which examined starting, performance, and durability.

The starting tests included cold, hot, and restart after refueling. For each test, the number of pulls to start each engine was reported. When possible, the test was run under both hot and cold ambient conditions. The performance testing included multi-position stability, acceleration characteristics, idle stability, wide open throttle stability, rated speed stability, and horsepower at rated speed. Finally, the durability testing included accelerated use testing, emissions testing per method J1088, and fuel degrading per ASTM D525. For durability testing, horsepower measurements were taken at the start and end of each test, fuel consumption was monitored at the start and finish of the test, and load cell information was recorded and test conditions were noted. (Appendix 12 contains the Poulan/Weed Eater test plan.)

The following is a summary of each company's test program. (Appendix 13 contains copies of each company's preliminary or final report, and a letter from PPEMA regarding the test porgram's findings.)

2. Echo - Kioritz

Test Description. Echo-Kioritz tested a CS3000 model chain saw with a 30.1 cc engine. One chain saw was evaluated on the CaRFG certification fuel and another was evaluated on conventional fuel. Echo-Kioritz conducted their test in Tokyo, Japan.

Results. Based on the results of the evaluation, Echo-Kioritz made the following conclusions:

- Reformulated fuels containing oxygenates will generally result in slightly leaner (= 1% CO) running engines. In engine models currently in use, this can be overcome by manual mixture settings on the carburetor. The need to use limited adjustable carburetors due to ARB emission regulations on small utility engines will require compensation in design of new model engines produced for sale in California to account for enleanment of combustion with CaRFG.
- Differences in wide open throttle and idle stability were difficult to detect between the CaRFG fuel and conventional fuel tested. Acceleration of engines using fuels tested was judged equivalent.
- In general, CaRFG starting performance was better than conventional fuel at 32 °F, but worse at 90°F. The two fuels were equivalent at 59°F.
- Testing showed that emissions of CO and HC were reduced using CaRFG by 39% and 8% respectively. NOx emissions increased by 23%.

The report findings did not indicate any major differences in durability between the CaRFG certification and conventional fuel.

3. Andreas Stihl

Test Description. Andreas Stihl tested a trimmer and a chain saw. The trimmer is used for residential lawn trimming, professional landscaping, and road maintenance with a displacement of 25 cc and a rated power of 1.2 hp. The chain saw is used for tree trimming, light felling, bucking, and limbing with a displacement of 44 cc and a rated power of 3.0 hp. Andreas Stihl conducted the testing in Germany.

Andreas Stihl reported that since the composition of the CaRFG certification fuel and federal RFG test fuel were similar, they would apply the results of the federal RFG program to CaRFG program. Thus, they did not test the CaRFG certification fuel for idle and wide open throttle stability, rollout testing, and startability testing. (Roll out refers to an evaluation of the RPM in various engine positions.)

Results. Andreas Stihl reported that, overall, no significant changes in technical parameters were observed related to the use of the CaRFG certification fuel.

However, based on the federal RFG results, they expect to receive complaints regarding starting difficulties using oxygenated fuels. It should be noted, however, that Andreas Stihl conducted its starting test, with only the federal RFG and not the CaRFG certification fuel.

4. Dolmar Makita

Test Description. In Hamburg, Germany, Dolmar Makita tested chain saws and brush cutters currently certified for sale in California.

Preliminary Results. The results of emission testing and stability testing show no significant differences between the CaRFG certification fuel and standard pump grade fuel. Field, durability, and compatibility test results are pending.

5. Homelite

Test Description. The Homelite test program evaluated the CaRFG certification fuel in a 30 cc electric start weed trimmer engine and a 38 cc chain saw. The users were asked to note differences in the performance characteristics between the fuels used. To date, the trimmer has been run for 40 hours, and the chain saw has been run for 30 hours using the CaRFG certification fuel. Homelite conducted their test program in Charlotte, North Carolina.

Preliminary Results. No noticeable difference in power has been detected between the CaRFG certification fuel and standard pump grade fuel. The CaRFG certification fuel has worked well at keeping the internal components of the engine clean; carbon deposits in the combustion chamber are easily cleaned off.

Operators have noted strong odors from the CaRFG certification fuel and complained about the odor. Reports of head aches and light-headedness have been noted.

6. Poulan Weed Eater

Test Description. Poulan Weed Eater tested 4 units (2 trimmers and 2 chain saws) using the test plan developed for evaluation of federal RFG.

Preliminary Results. To date, the test data obtained using the CaRFG certification fuel compared very closely to that of standard unleaded pump grade gasoline with respect to performance.

The results from the federal RFG test program showed less than favorable performance characteristics. The federal RFG demonstrated poor starting and acceleration. Poor performance characteristics increased with time, showing a continuation of “leaning out” of the engine. The chain saws experienced vapor lock problems with the 15 RVP fuel. They also experienced hot start and roll out problems.

CHAPTER IV

PLEASURE CRAFT AND SMALL MARINE ENGINES TEST PROGRAMS

A. Introduction

This chapter discusses the 2 pleasure craft and small marine engine test programs, which were conducted in cooperation with Mercury Marine, the manufacturer of the small marine engines used in the test fleet.

B. Background

Pleasure craft and small marine engines comprise about 13 percent of the off-road vehicle fleet. According to the Department of Motor Vehicles, approximately 60 percent of gasoline-powered pleasure craft use outboard engines, and the remaining 40 percent use inboard engines. Although there are approximately 20 to 30 manufacturers of gasoline-powered pleasure craft, Mercury Marine is one of the largest manufacturers.

Inboard engines are housed within the body of the boat. Typically, inboard engines use 4-stroke technology with 4, 6, or 8 cylinders. The horsepower rating generally ranges from 100 to 500 hp, with around 300 hp the most common. These engines are derived from automobile engine technology.

Nearly all outboard engines use 2-stroke engine technology. These engines generally have 1 to 6 cylinders with horsepower ratings from 1 to 250 hp. The historical sales records released by the United States Environmental Protection Agency report that there is a fairly even distribution of engine population over the lower horsepower engines (4 to 75 hp). (See Appendix 14 for more details.)

C. Program Fleets

The first program was conducted at Paradise Watercraft, which included test and control fleets. The second program was conducted at Lake Cachuma Boat Rentals, which did not have a control fleet. Both fleets are primarily used in a recreational environment.

D. Paradise Watercraft Boat Rentals and South Shore Parasailing

1. Test Description

Paradise Watercraft conducted a 10 week test program. As South Lake Tahoe is about 6,200 feet above sea level, the testing evaluated the performance of the test fuel at high altitude. The test fleet consisted of 8 boats at Ski Run Marina, and the control fleet consisted of 5 boats at Camp Richardson Marina. Table 6 summarizes the test and control fleets. The test fleet used

CaRFG test fuel, and the control fleet used conventional fuel. Outboard motors were mounted on Bayliner boats which seat between 4 to 13 people, with the exception of the Force 15 motor, which was mounted on a Caroline Skiff. The inboard 454 cubic inch Chevrolet motor was installed in a Regal boat, which was used for parasailing.

The Paradise Watercraft fleet is used for recreational boating with a mixture of cruising and water skiing. The duty cycle of these boats tends to be more rigorous than boats owned and operated by average recreational consumers.

Table 6
Paradise Watercraft Fleet

Engine	**Test Fleet (Ski Run Marina)**	**Control Fleet Camp Richardson Marina)**
Force 150	1	1
Force 120	4	3
Force 70	1	1
Force 15	1	0
Inboard (335 hp)	1	0
Total	**8**	**5**

Source: California Air Resources Board. September 1, 1995. *California Air Resources Board Oracle Database Systems/Reformulated Gasoline Project.* Sacramento, California.

At the Ski Run Marina test site, fuel use was logged on a per-rental basis. Hour meters were installed on all participating engines to track hours of operation. Every 2 weeks, hour meter and fueling data were collected. The test fleet accumulated a total of 858 hours of operation, with each boat averaging 107 hours. The test fleet used 4,363 gallons of CaRFG test fuel. The control fleet accumulated a total of 489 hours for an average of 119 hours per boat. The number of gallons used at the control site was not logged.

Inspections. The boats were monitored every 2 weeks and inspected 3 times during the test period. The inspections consisted of a preliminary visual inspection of the engine. The engine's performance characteristics under starting, idling, and operating under load were then evaluated.

2. Results

The fleet operators did not report any difference in performance with the test fuel as compared to conventional gasoline at high altitude. The inspections did not show any significant deterioration of engine condition. (Appendix 15 contains the data collected for this test program.)

Incidents. During the test period, 4 control incidents and 4 test incidents were reported; however, only 1 incident from the control fleet was defined as possibly fuel-related. This incident involved a leaking carburetor, which was considered a normal repair for the age and condition of the engine. (Appendix 16 contains a report on the incidents.)

E. Lake Cachuma Boat Rentals - Pleasure Craft

1. Test Description

The Lake Cachuma Boat Rentals test program was conducted for 10 weeks. The Lake Cachuma test fleet was comprised of boats equipped with small outboard engines.

The Lake Cachuma Boat Rentals test fleet included 95 boats; 88 small fishing boats using 5 to 9.9 horsepower outboard motors and 7 pontoon boats with 25 horsepower outboard motors. The boats were equipped with Mercury Marine 2-stroke engines ranging from 1983 to 1994 model years.

The Lake Cachuma Boat Rentals fleet is primarily used in a recreational rental environment, and fuel use is estimated on a per rental event basis. The test fleet used 3,572 gallons of test fuel. The boats averaged 20 to 30 hours of use per month. Although the test fleet was operated for only 10 weeks, the hours placed on these engines approximate as much as 2 years of average consumer use.

Inspections. During the test period, a total of 7 inspections were conducted at Lake Cachuma, and 1 comparison inspection was conducted at nearby Lake Casitas. Full inspections were conducted every 2 weeks. Hour meters were installed on a sample of engines for record keeping purposes. For the motors not equipped with hour meters, the inspectors used the log books to determine the hours of use and whether or not repairs or adjustments to the motors may have been fuel related.

2. Results

The fleet manager and operators did not report any abnormal performance or maintenance problems which could be attributed to the test fuel. During the test program, several of the engines showed signs of seepage. However, after further investigation, the seeps were determined non-fuel related. (Appendix 17 provides a discussion of the seeps and Appendix 18 summarizes data collected for this program.)

Control Fleet. Although there was no official control fleet, the inspection team along with a representative from Mercury Marine visited the nearby Lake Casitas Boat Rentals, which was similar to the Lake Cachuma site in terms of equipment and rentals. The engines at this site were in similar condition as those at Lake Cachuma. Mercury Marine verified that the noted seeps were not fuel related.

CHAPTER V

PERSONAL WATERCRAFT TEST PROGRAM

A. Introduction

This chapter discusses the Paradise Watercraft personal watercraft test program.

B. Background

In general, the existing personal watercraft fleet in California includes 2-stroke engines with either a 2 or 3 cylinder configuration. The engine displacement ranges from 400 cc to 750 cc, with the highest volume of sales in the 650 cc to 700 cc range. Personal Watercraft units are designed as sport performance or touring models.

C. Paradise Watercraft Boat Rentals and South Shore Parasailing

1. Test Description

The Paradise Watercraft test program was conducted at South Lake Tahoe, in cooperation with Arctco Incorporated, who manufactures the Tigershark personal watercraft. Testing lasted 10 weeks.

The Paradise Watercraft test fleet comprised 11 personal watercraft. Ten of the 11 the units were new, and the other unit was a 1994 model. Eight of the 11 units were the Tigershark Montego model (639 cc) and 3 were of the Tigershark Monte Carlo model (644 cc). (See Appendix 19 for the specification for Tigershark personal watercraft.)

The test fleet undergoes a more rigorous duty cycle than privately-owned units. Additionally, because South Lake Tahoe is 6,200 feet above sea level, the fuel's performance at cold temperatures and high altitudes was evaluated.

To properly monitor the units, hour meters were installed on all units. Hour meters were read every two weeks. The units logged a total of 964 hours, averaging 96 hours each for the 10 week period. Approximately 750 gallons of fuel was used, with the fleet using approximately 75 gallons of fuel per week. At the request of Arctco Inc., pressure readings were taken from the cylinders to check for deterioration of engine performance during the second inspection. Table 7 lists the hours logged by each unit and the results of the pressure test.

Inspections. Every 2 weeks a sample of units were inspected while all of the units were inspected every 2 months. The final inspection of all units took place August 31, 1995 at the termination of the program.

Table 7
Personal Watercraft Test Fleet

Model	Total Hours	Pressure Test Results (psi)	
		Cylinder #1	Cylinder #2
Montego	123	125	125
Montego	n/a	125	125
Montego	117	125	125
Montego	121	125	125
Montego	23	125	125
Montego	98	125	125
Montego	96	125	125
Montego	86	n/a	n/a
Monte Carlo	181	145	148
Monte Carlo	49	140	140
Monte Carlo[1]	70	145	145

Source: California Air Resources Board. September 1, 1995. *Air Resources Board Oracle Database System/Reformulated Gasoline Project* . Sacramento, California.

1. This unit was a 1994 model year while all other units were new, 1995 units.

2. Results

The pressure testing of cylinders did not reveal any unusual variations from expected readings. In addition, the inspections did not show any deterioration of engine condition.

Incidents. One incident was reported during the test period, which was not fuel-related. Arctco Incorporated indicated that the piston ring failed due to normal wear out. (Appendix 20 includes a summary of data collected in the Paradise Watercraft personal watercraft test program.)

CHAPTER VI

INDUSTRIAL, CONSTRUCTION, AND AGRICULTURAL EQUIPMENT TEST PROGRAMS

A. Introduction

This chapter discusses the industrial, construction, and agricultural equipment off-road test programs.

B. Background

1. Industrial and Construction Equipment

The industrial and construction category contains 70,000 gasoline-powered vehicles and equipment. Most of these engines are used in smaller equipment such as forklifts and generators, which dominate this category, followed by compressors. Nearly 80 percent of the forklifts in California have engines in the 42 hp to 100 hp range. Approximately 90 percent of generators range from 25 hp to 40 hp. (See Appendix 1.)

2. Agricultural Equipment

The agricultural equipment category includes 13,000 gasoline-powered vehicles and equipment; this represents only 10 percent of 130,000 agricultural vehicles in California. The majority of gasoline-powered engines are in the smaller engine category, ranging from 25 hp to 40 hp. Most of the gasoline-powered equipment are fairly old since most manufacturers no longer make gasoline-powered models. (See Appendix 1.)

C. Test Programs

Off-road test programs were conducted at Caltrans and at CSU Fresno. The Caltrans test program included industrial and construction equipment while the CSU Fresno test program included industrial, construction, and agricultural equipment.

In addition to the programs at Caltrans and CSU Fresno, 2 fleets participating in the On-Road test program included industrial equipment that used CaRFG. GTE and Pacific Bell each had utility trucks equipped with on-board generators which used fuel from the vehicle gas tank or from gas tanks housed in the equipment. Pacific Bell's fleet included 30 generators, and GTE included 39 generators in their fleet. The generators tested in this manner were manufactured by Onan. Fleet operators and managers noted no increase in equipment maintenance or repairs as a result of using the CaRFG test fuel.

D. Caltrans Industrial and Construction Test Fleet

1. Test Description

Testing was initiated in March 1995 and was completed at the end of August 1995. The Caltrans test fleet consisted of 1 forklift, 2 concrete mixers, 1 sweeper, and 1 generator-powered pass sign. Table 8 summarizes the fleet and the number of hours accumulated during the test program.

Table 8
Caltrans Test Fleet

Equipment	Manufacturer	Model Year
Forklift	TCM/Nissan	85
Sweeper	American Lincoln	84
Concrete Mixer	Briggs & Stratton	73
Concrete Mixer	Wisconsin	64
Generator (Pass Sign)	Lear Siegl	81

Source: California Air Resources Board. September 10, 1995. *Air Resources Board Oracle Database System/Reformulated Gasoline Project* . Sacramento, California.

Inspections: During the 5 month test period, 2 inspections of the Caltrans equipment were conducted.

2. Results

The inspectors did not note any deterioration in the condition of the engines. The fleet personnel did not report any repair incidents. Additionally, the fleet personnel did not note any changes in performance while using the test fuel. (A summary of data collected at Caltrans is located in Appendix 21).

E. CSU Fresno Industrial, Construction, and Agricultural Test Fleets

1. Test Description

Testing began in May 1995 and continued through August 1995. Sixteen industrial and construction vehicles and equipment were tested. This fleet is used in a typical utility setting. In the agricultural category, the test fleet included 2 tractors which received limited hours of use on the test fuel. Most of the CSU Fresno agricultural equipment is used intermittently, which is typical of gas-powered agricultural vehicles. Table 9 summarizes the vehicles and equipment included in the CSU Fresno off-road test program. Hourly meter or odometer readings were not available.

Table 9
CSU Fresno Industrial, Construction, and Agricultural Vehicles

Vehicle (manufacturer)	Number of Units
Small Utility Carts (Cushman, Kawasaki)	9
Forklifts (Caterpillar, Clark, TCM)	4
Skip Loader (Ford)	1
Bobcat (Melroe)	1
Hi Jet (Daihatsu)	1
Agriculture (Ford, Farmall)	2

Source: California Air Resources Board. September 10, 1995. *Air Resources Board Oracle Database System/Reformulated Gasoline Project.* Sacramento, California.

Inspections: The CSU Fresno fleet was inspected at the start and end of the test program. In addition, the fleet was visited every 2 weeks to obtain information from the fleet personnel regarding vehicle and equipment performance.

2. Results

The inspectors did not report any deterioration in the engine condition. Additionally, the CSU Fresno staff did not report any repair incidents. (See Appendix 22 for a summary of data collected in the CSU Fresno Industrial, Construction, and Agricultural test program.)

CHAPTER VII

SNOWMOBILES

A. Introduction

This chapter discusses the Lake Tahoe Winter Sports Center snowmobile test program.

B. Background

In general, the existing snowmobile fleet includes 2-stroke engines. Snowmobile engines range from 1 to 4 cylinders, with the majority using 2 cylinders. Most models have engine sizes between 400 cc and 600 cc. The majority of snowmobiles in California are used for recreation and are of the sport performance variety.

C. Lake Tahoe Winter Sports Center Test Program

1. Test Description

A 6 week test program was conducted at the Lake Tahoe Winter Sports Center in Hope Valley, California and co-sponsored by Arctco Inc., manufacturer of Arctic Cat snowmobiles. Testing began in April 1995 and concluded in June 1995. The Lake Tahoe Winter Sports center fleet comprised 10 snowmobiles. Nine of the vehicles were Arctic Cat 440s and 1 was a larger Arctic Cat 550.

During the test program, the 10 vehicles accumulated a total of 25,475 miles with an average of 2,548 miles each, which represents significantly more miles than the average consumer. Table 10 describes the fleet and number of miles accumulated per snowmobile. The miles traveled were logged by tracking the number of tours that each vehicle participated in. Hope Valley is approximately 7,500 feet above sea level. Thus, the CaRFG test fuel was evaluated at high altitude, cold temperatures, and a rigorous duty cycle. Utility uses of snowmobiles often require vehicles to perform 8 to 10 hours per day and for several days for certain periods of the winter.

Table 10
Lake Tahoe Winter Sports Center Test Fleet and Total Miles

Snowmobile (unit number)[1]	**Miles**
Arctic Cat 440 (14)	2550
Arctic Cat 440 (17)	3175
Arctic Cat 440 (18)	2725
Arctic Cat 440 (19)	1525
Arctic Cat 440 (22)	1975
Arctic Cat 440 (32)	2275
Arctic Cat 440 (76)	2200
Arctic Cat 440 (79)	2900
Arctic Cat 440 (80)	2650
Arctic Cat 550 (Guide)	3,500
Total	25,475

Source: California Air Resources Board. September 1, 1995. *California Air Resources Board Oracle Database Systems/Reformulated Gasoline Project.* Sacramento, California.

1. Unit numbers used to connect data to individual vehicles.
2. Approximate accumulated miles during the test program

Inspections. The test program included an initial inspection and final inspection.

2. Results

The inspectors did not note any deterioration in engines and the fleet operators did not report any incidents. The fleet operators noted a decrease in smoke from the engine; which was identified as a benefit of the CaRFG test fuel. The fleet operators also noted slight acceleration losses. (Appendix 23 contains a summary of data collected during the test program.)